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**Volume 5**
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**Number 3**

# *Species Hybridization in the White Pines*

BY
JONATHAN W. WRIGHT

SPECIES HYBRIDIZATION has always been an important part of forest genetics work at the Northeastern Forest Experiment Station. The genetic program was started at the station in 1937, but hybridization in some genera was dropped because it showed little promise. In the white pines, however, species hybridization has been very promising and work in this line has increased steadily.

The 5-needled white pines are favorites of tree hybridizers because of their rapid growth, excellent wood qualities, easy crossability, relative completeness of arboretum collections, and demonstrated need for genetic improvement in certain characteristics, especially rust and weevil resistance.

Species hybridization is intended to complement rather than replace other work on the genetics of white pines. Also, some species hybridization work is necessary for a fuller knowledge of the taxonomy and racial variation of the white pines of the Southwest, whose limits are not fully known.

The individual tree selection studies and provenance tests now in progress in eastern white pine (*Pinus strobus* L.) and western white pine (*P. monticola* Dougl.) will help in the proper utilization of species hybrids, which should be based on selected individuals of selected ecotypes of both parent species. Studies of ecotypic variation within a single species will help us understand the factors causing species differentiation and the relationships between species.

This paper is a report on the Northeastern Forest Experiment Station's white pine hybridization studies conducted near Philadelphia from 1947 through 1956. It contains information on the flowering and fruiting habits of several white pine species, on species crossability relationships within the section *Cembra*, and on juvenile performance of the hybrids produced. Other papers dealing with the station's white pine breeding work have been written by Wright (1953) and by Wright and Gabriel (1957).

## Materials and Methods

*Selection of crosses and parents.* In selecting species combinations to be attempted, preference was given to: (1) previously successful combinations between rapidly growing species; (2) previously untried combinations between closely related, rapidly growing species; and (3) previously unsuccessful combinations, up to a limit of

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The author, now Associate Professor of Forestry at Michigan State University, East Lansing, Mich., was a Geneticist at the Northeastern Forest Experiment Station, Forest Service, U.S. Dept. of Agriculture, when this report was prepared. The work described was carried out in cooperation with the Morris Arboretum, University of Pennsylvania, at Philadelphia, Pa.

Other Northeastern Station personnel who took part in this work include E. J. Schreiner, James Brown, F. E. Cunningham, W. J. Gabriel, and H. E. Kettlewood. Many of the techniques and record forms used were based on those developed by J. W. Duffield, E. J. Schreiner, and A. G. Snow. Grateful acknowledgment is also made to the arboreta that provided free use of breeding stock; and to the New Jersey Department of Conservation and Economic Development, which provided nursery space and care at its Washington Crossing State Forest Tree Nursery.

10 tree x tree combinations. Crosses were usually made in the direction of early flowering male x late flowering female, but some combinations were tried that required the storage of pollen for a year.

Except for a few native eastern white pines in the Pocono Mountains of eastern Pennsylvania, the trees used as parents were planted specimens of unknown provenance located in or near Philadelphia (Table 1). Most of these planted specimens were in the Morris Arboretum, Philadelphia; Westtown School Arboretum, Westtown, Pa.; Haverford College Arboretum, Haverford, Pa.; and Scott Arboretum, Swarthmore College, Swarthmore, Pa. The identity of many of the parents was checked by competent authorities such as Alfred Rehder.

*Pollen handling.* Male catkins were collected when nearly ready to open. They were dried in the laboratory by being spread out on paper or packed loosely in large sausage-casing pollination bags. The thoroughly dried pollen was sieved, placed in cotton-stoppered glass vials, and stored at 25 to 40 percent relative humidity and about 40°F. Since June 1954, pollen to be preserved for a year or more was stored at undetermined relative humidities in a freezer kept about 0°F. No *in vitro* pollen-germination tests were made.

Reasonable precautions were taken against pollen contamination. These included washing hands, sieves, and table tops between the handlings of different pollen lots, and separation of batches of drying catkins by 3 or 4 feet in a closed room. Judging from the almost complete lack of filled seed in the many unsuccessful combinations and from the few obvious contaminants appearing in the nursery, the precautions were sufficient to keep the amount of contamination low (probably less than 1/10 of one percent).

For intraspecific crosses, the pollens were kept separate by individual trees. For interspecific crosses, pollens of two or three trees were mixed; this increased the likelihood of obtaining viable seed.

Inexpensive medicine droppers with a hole 0.3 to 0.4 millimeter in diameter were used as pollen applicators. With such applicators, filled by suction in the field, a 7 cubic-centimeter vial of pollen lasted for 40 or 50 pollination bags.

*Bagging and pollination.* Synthetic sausage-casing pollination bags were used to protect the female strobili from outside

*TABLE 1. Number, maximum size, and flowering size of 5-needled pine parents used in the interspecific hybridization studies, 1947-56.*

| Species *Pinus*— | Trees | Height | Diameter breast high | Age | Height of trees when quantity flower production began | |
|---|---|---|---|---|---|---|
| | | | | | Female | Male |
| | *Number* | *Feet* | *Inches* | *Years* | *Feet* | *Feet* |
| *koraiensis* | 4 | 27 | 8 | 18 | -- | 20 |
| *cembra* | 3 | 31 | 9 | 48 | 20 | 20 |
| *flexilis* | 19 | 40 | 12 | 18 | 30 | 30 |
| *armandi* | 2 | 5 | 1 | 5 | -- | 2 |
| *ayacahuite* | 1 | 52 | 23 | 34 | -- | -- |
| *parviflora* | 3 | 24 | 7 | 34 | 20 | 20 |
| *peuce* | 7 | 22 | 5 | 15 | 8 | -- |
| *griffithii* | 12 | 70 | 31 | 50 | 30 | 50 |
| *monticola* | 5 | 35 | 12 | 23 | 25 | -- |
| *strobus* | 38 | 75 | 22 | 50 | 30 | 50 |

pollination. These bags were applied on the current year's growth when the female strobili were in stage I (buds just starting to expand) or in stage II (tip of female strobile visible), 1 to 2 weeks prior to anthesis. In eastern white pine and limber pine (*P. flexilis* James), most of the bags were left in place until cone maturity (Wright and Gabriel 1957); but in other species they were removed after the flowers reached stage VII (bracts hidden, scales swollen shut).

The flowers were pollinated in stage IV (all bracts and scales visible, bracts larger than scales) or stage V (bracts and scales of equal length, scales not swollen). Pollen was applied through small holes in the pollination bags; the holes were sealed immediately with cotton or scotch tape.

Each bag included the elongating terminal bud and two to four lateral buds. In heavily flowering limber, Mexican white (*P. ayacahuite* Ehrenb.), Japanese white (*P. parviflora* Sieb. and Zucc.), and Macedonian white pine (*P. peuce Griseb.*) trees, these pollination bags contained 5 to 10 female flowers. In heavily flowering Himalayan white pine (*P. griffithii* McClel.) and eastern white pine trees, they contained 10 to 20 female flowers.

*Cone and seed handling.* Cones were collected without prior bagging from 1 to 7 days before they were scheduled to open. Cone and seed losses due to premature opening and squirrels were slight. Cones were dried and seeds extracted at room temperature.

The cleaned, full-sized seeds were separated into "empties" and "fulls" by immersion in 95 percent ethyl alcohol. Then the filled seeds (sinkers) were thoroughly air-dried and placed in sealed glass bottles by storage at 36° F until stratification. Seed was cold-water stratified (Rudolf 1950) for 1 to 2 weeks prior to sowing.

*Nursery treatment and field testing.* Prior to 1954, the seeds were germinated in the greenhouse and transplanted into replicated shaded nursery beds at the Morris Arboretum. Since 1954, the seeds have been spring-sown directly into unreplicated nursery beds at the Washington Crossing Nursery of the New Jersey Department of Conservation and Economic Development. At intervals of 1 year or less, nursery notes were taken of the number living, height, growth characteristics, and taxonomic characteristics of each seedlot. For ease of analysis, this information was recorded in coded form on cross-section paper.

When 3 or 4 years old, the hybrids were outplanted in permanent replicated field tests in Washington Crossing, N. J.; Williamstown, Mass.; Norfolk, Conn.; Johnsonburg, Pa.; Villanova, Pa.; and New Haven, Conn. These plantings will provide the basis for making the final judgment of the hybrids produced.

## Results

*Flowering and fruiting habits of the parent species.* Eastern white pine, western white pine, and Himalayan white pine produced female strobili in profusion for several years before they started to produce pollen (Table 1). In eastern white pine this habit was so pronounced that almost all the Philadelphia parents were inadequately wind-pollinated. Unisexuality prevented selfing experiments on most of the trees used as parents.

In most species the male catkins were produced in the lower two-thirds or three-quarters of the live crown. In Swiss stone pine (*P. cembra* L.) alone were the catkins borne only on the upper branches. The female strobili were borne in the upper one-tenth of the live crown of Swiss stone pine and Korean white pine (*P. koraiensis* Sieb. and Zucc.); in the upper one-third of the live crown of eastern white and limber pine; or concentrated in the top but borne over the entire live crown of western white, Macedonian white, Himalayan white, Mexican white, and Japanese white pine, and also Armand pine (*P. armandi* Franch.). In heavily flowering trees of most species, nearly all vigorous branches in the flowering portions of the crown produced female strobili at their tips; in such

cases, it was possible to tell the approximate number of strobili on each branch merely by its position in the crown. In limber pine, however, only a small number of the vigorous branches in the cone-producing portion of the crown actually produced female strobili.

In all species, many of the older trees flowered annually or biennially but fruited at more infrequent intervals. Trees rarely matured over 90 percent of their cones, and 0 to 10 percent cone crops were all too common. In many instances two cone insects—*Conophthorus coniperda* (Schw.) and *Dioryctria* sp.—were responsible for the cone mortality, but in other cases the cause is still unknown. Continuous bagging of the flowering branches resulted in partial control of the cone insects in eastern white and limber pines (Wright and Gabriel 1957).

The period of flowering usually lasted 2 to 3 days for a single tree and 4 to 5 days for all trees of a species. The differences in time between the inception of receptivity of the female strobili and the inception of pollen shedding were usually too slight to prevent self-pollination or cross-pollination between adjacent trees belonging to the same species. Cold, rainy weather at flowering time usually extended the period of bloom for a tree or a species by only one day. A succession of two or three rainy days at flowering time effectively prevented controlled pollination experiments on a species for that season.

In different years during the period 1947 to 1956, the date on which Swiss stone pine, the earliest flowering white pine species, began to flower varied from May 9 to May May 28; the average date was May 22 (Table 2). The average spread between the earliest flowering and the latest flowering species was 9 days. Blooming sequence of different species remained approximately the same from year to year. The time of flowering of a single species relative to other species might vary by one day or two, but the late eastern white pine never started to produce pollen before the early flowering Himalayan white pine.

*TABLE 2. Average flowering and cone-opening dates of 5-needled white pine species in the Philadelphia area, 1947-56.*

| Species *Pinus*— | Average dates of first— Pollen shedding | Cone opening |
|---|---|---|
| *cembra* | May 22 | Aug. 27 |
| *griffithii* | May 26 | Oct. 15 |
| *parviflora* | May 27 | Aug. 24 |
| *armandi* | May 28 | ... |
| *koraiensis* | May 28 | ... |
| *flexilis* | May 29 | Aug. 22 |
| *strobus* | May 29 | Aug. 22 |
| *ayacahuite* | May 30 | Sept. 19 |
| *monticola* | May 31 | Aug. 18 |

Shortness of the white pine flowering season affected the conduct of the pollination work in two ways. First, only two or three different species could be worked intensively in any given season. For example, control-pollinating all available limber pines took so much time that it was impossible to devote adequate time to the pollination of eastern white pine. Second, reciprocal crosses could be made with fresh pollen more easily than in the hard pines or spruces that have a longer flowering season. For example, it was almost always possible to collect pollen from an exceptionally early eastern white pine or limber pine for use on a Himalayan white pine female.

The date of first cone opening for eastern white pine in Philadelphia varied in different years from August 17 to September 1; the average date was August 22 (Table 2). In this species cone maturation took place 1 to 3 weeks earlier than in native stands in the Northeast. There is not sufficient published information for comparing dates of cone ripening in Philadelphia and in native stands in the other species.

*Seed production.* Seed sets following wind and controlled pollinations in the Philadelphia area are given in Table 3. This table

brings out several noteworthy facts regarding seeding habits of the various species.

The low seed sets of eastern white pine in Philadelphia are both interesting and puzzling. These planted specimens are within 50 miles horizontal distance and about 500 feet vertical distance of native eastern white pine, and grow vigorously.

*TABLE 3. Results of white pine crossing work in the Philadelphia area, 1947-56.*

| Female parent *Pinus*— | Male parent: None | Wind | self | *koraiensis* | *cembra* | *flexilis* | *armandi* | *ayacahuite*[1] | *parviflora* | *peuce* | *griffithii* | *strobus* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *flexilis* | 53 | 1,180 | .... | 23 | 53 | 231 | 159 | .... | .... | .... | 1,239 | 246 |
| | 0.0 | 42.0 | .... | 0.0 | 9.4 | 22.0 | 23.2 | .... | .... | .... | 27.8 | 15.5 |
| | .... | 17.7 | .... | .... | .0 | 27.8 | 44.0 | .... | .... | .... | 31.3 | 27.2 |
| | .... | 9.1 | .... | .... | .0 | 1.4 | .4 | .... | .... | .... | 4.1 | .02 |
| *ayacahuite*[1] | 24 | 1,360 | .... | 15 | 6 | 40 | .... | .... | .... | .... | 212 | 130 |
| | .0 | 53.4 | .... | 40.0 | .0 | 20.0 | .... | .... | .... | .... | 20.8 | 31.6 |
| | .... | 10.8 | .... | 15.2 | .... | 42.0 | .... | .... | .... | .... | 17.4 | 14.4 |
| | .... | [2]18.9 | .... | .0 | .... | 1.1 | .... | .... | .... | .... | 12.7 | 17.0 |
| *parviflora* | 42 | ? | .... | .... | 52 | 61 | .... | .... | .... | 8 | 59 | 220 |
| | .0 | ? | .... | .... | 5.8 | 31.2 | .... | .... | .... | 37.5 | .0 | 23.2 |
| | .... | 4.0 | .... | .... | 7.0 | 2.2 | .... | .... | .... | 2.0 | .... | 7.0 |
| | .... | .5 | .... | .... | .0 | .0 | .... | .... | .... | .0 | .... | .0 |
| *peuce* | .... | 225 | .... | 6 | .... | .... | .... | .... | 21 | .... | 50 | 253 |
| | .... | 49.4 | .... | .0 | .... | .... | .... | .... | 23.8 | .... | 54.0 | 37.2 |
| | .... | 15.9 | .... | .... | .... | .... | .... | .... | 11.6 | .... | 22.5 | 21.2 |
| | .... | [2]4.7 | .... | .... | .... | .... | .... | .... | .0 | .... | .6 | 5.3 |
| *griffithii* | 139 | 4,000 | 48 | 56 | 49 | 253 | 56 | 19 | 52 | .... | 513 | 1,593 |
| | 6.5 | 41.8 | 33.3 | 8.9 | 10.2 | 18.5 | 16.1 | 68.4 | 13.5 | .... | 21.8 | 13.7 |
| | .0 | 11.9 | 35.0 | 17.4 | 1.0 | 56.5 | 36.1 | 13.8 | 17.8 | .... | 15.4 | 22.4 |
| | .0 | 4.1 | 1.9 | 0.0 | .0 | .2 | .0 | .0 | 2.3 | .... | 6.9 | 2.3 |
| *monticola* | .... | 445 | .... | .... | .... | .... | 49 | 28 | .... | .... | 174 | 111 |
| | .... | 4.5 | .... | .... | .... | .... | 0.0 | 10.7 | .... | .... | 19.4 | 4.5 |
| | .... | 27.2 | .... | .... | .... | .... | .... | 38.7 | .... | .... | 52.8 | 48.0 |
| | .... | [2]14.6 | .... | .... | .... | .... | .... | 3.0 | .... | .... | 17.6 | 13.0 |
| *strobus* | 175 | 11,500 | 96 | 658 | 334 | 831 | .... | 277 | 302 | 26 | 969 | 1,514 |
| | 17.7 | 10.9 | 17.7 | 28.0 | 29.0 | 18.1 | .... | 26.0 | 21.4 | 73.1 | 36.9 | 15.1 |
| | .0 | 3.5 | 14.2 | 4.9 | 6.0 | 7.7 | .... | 7.4 | 7.4 | .4 | 3.8 | 3.9 |
| | .0 | [2]1.1 | 4.8 | .3 | .0 | .1 | .... | 4.8 | 1.4 | .0 | 0.9 | 2.3 |

Legend:

| | |
|---|---|
| 1,180 | Flowers pollinated |
| 42.0 | Cone set, percent |
| 17.7 | Empty seeds per cone |
| 9.1 | Full seeds per cone |

[1]Tentative identification.
[2]Presumably x *strobus*.

However, even when control-pollinated, they produced only three to five good seeds per cone, compared with 20 to 70 good seeds per cone for eastern white pine in various parts of the species' natural range.[1] One possible explanation may be that the warm summer temperatures in Philadelphia hastened cone maturation more than seed maturation. But continuous bagging of the cones from pollination to maturity, which probably raises the temperature of the developing cone, also increased seed set (Wright and Gabriel 1957).

There was need to ascertain whether or not interspecific as well as intraspecific seed sets were higher in native stands than in planted Philadelphia stands. Thus, pollen of eastern white, Himalayan white, western white, Japanese white, and Mexican white pines was applied to native eastern white pine trees near Brodheadsville, Pa., about 60 miles north of Philadelphia, and to eastern white pines in Philadelphia. The results of this 1-year test were surprising. Intraspecific seed sets in the native trees were three times as great as those obtained in Philadelphia; interspecific seed sets were in every case lower than those obtained in Philadelphia.

There was no apparent correlation between the ability of a tree or species to produce large numbers of good seeds per cone and its age, vigor, flowering ability, or distance from its native range. For example, in Himalayan white pine two young and three old trees produced more than 15 good seeds per cone; other young and old trees of the same apparent vigor produced only 0 to 5 good seeds per cone. With regard to the relation between seed-setting ability and distance from the native range of the species, it should be pointed out that the warm-climate Mexican white pine and the cool-climate western white pine produced many more good seeds per cone than did the almost native eastern white pine.

These vagaries of seed setting are discussed here because they are important in a tree-breeding program; they illustrate the complexity of the physiology of seed production. Evidently no simple temperature or day-length hypothesis will be sufficient to explain the unanswered questions regarding seed production in a single species, let alone all white pines.

*Fresh versus year-old pollen.* In most cases, the sets of filled seeds were higher —appreciably so in three cases—after pollination with fresh rather than with year-old pollen (Table 4). On the other hand, there were slight differences—often in favor of the year-old pollen—in total seed set per cone. These *in vivo* tests only partially confirm the *in vitro* results of Duffield and Snow (1941) and of Duffield (1954), who found little deterioration in the viability of pine pollens stored a year under suitable conditions.

*Species crossability pattern.* The white pine interspecific crossing work done by the Northeastern Station and other agencies is summarized in Tables 3, 5, and 6. In general, the results of different workers who have attempted the same crosses are confirmatory. The exceptions involve cases in which one worker tried few tree x tree combinations of a cross.

Of 120 possible species or variety combinations (counting reciprocal crosses as single combinations) listed in Table 7,

17 gave hybrids
24 failed
7 gave undetermined results
2 were attempted too recently for cones to be harvested, and
70 have not been attempted.

In the Northeast, the job of working out the species crossability pattern is nearly completed. Fifty-nine of the crosses that have not been attempted involve species or varieties known to be non-hardy (Formosan white pine, *P. formosana* Hayata; Chiapas pine, *P. strobus* var. *chiapensis* Martinez) or very slow-growing (whitebark pine, *P. albicaulis* Engelm.; dwarf stone pine, *P. pumila* Regel; Swiss stone pine). It is

[1]Northeastern Forest Experiment Station, unpublished data.

*TABLE 4. Number of seeds per cone after pollination with fresh and year-old pollen*[1].

| Female parent *Pinus*— | Male parent *Pinus*— | Pollination date | Total seeds | | Full seeds | |
|---|---|---|---|---|---|---|
| | | | Fresh pollen | Year-old pollen | Fresh pollen | Year-old pollen |
| | | *Year* | *Number* | *Number* | *Number* | *Number* |
| *Peuce* | *strobus* | 1953 | .... | 16.4 | .... | 3.9 |
| | | 1954 | 18.9 | .... | 3.4 | .... |
| *griffithii* | *griffithii* | 1951 | 19.1 | 31.6 | 6.2 | 3.8 |
| *griffithii* | *strobus* | 1949 | 70.0 | .... | 9.3 | .... |
| | | 1950 | .... | 28.0 | .... | 1.6 |
| *ayacahuite* | *strobus* | 1948-1952 | 20.0 | .... | 16.6 | .... |
| | | 1953 | .... | 8.6 | .... | 2.7 |
| *strobus* | *strobus*[2] | 1953 | 17.7 | 23.5 | 10.2 | 7.7 |
| *strobus* | *strobus*[2] | 1954 | 28.0 | 29.4 | 24.4 | 13.7 |
| *strobus* | *strobus*[2] | 1955 | 27.5 | 34.8 | 16.5 | 14.0 |

[1]The results are based on totals of 242 and 244 cones from pollination by fresh and year-old pollen, respectively. Each comparison involves the same female parents and a single lot of year-old pollen. In each comparison the year-old and fresh pollens were from different trees.

[2]These pollinations were made on native trees in the Pocono Mountains of Pennsylvania. Therefore the seed sets are appreciably higher than those recorded in Table 3 for Philadelphia trees.

doubtful that hybrids from those species would be valuable in this region's forestry programs.

Except for those crosses involving sugar pine (*P. lambertiana*, Dougl.), all the attempted hybridization between species of the series *Strobi* have been successful, or probably successful, and most have given moderately high seed sets. Yet only a few of the crosses involving sugar pine or species in other series have been successful; only one such cross (*P. flexilis* x *griffithii*) has given high enough seed sets to indicate that there is much possibility of mass-producing the $F_1$ hybrids. Presumably crosses involving the 5-needled white pines and the hard pines or the non-5-needled soft pines would stand little chance of success.

For the present it appears that major emphasis should be on crosses involving the series *Strobi* and on a very few other crosses.

*Statistical reliability of the crossability data.* For various reasons many tree x tree combinations between crossable species fail to produce viable seeds. Failures are mostly due to non-viable pollen, poor weather during pollination or seed development, inadequate pollination, insect damage to cones, physiological cone drop, and incompatabilities between trees. Complete failure of a given species combination may be due to these reasons or to lack of species crossability. Only if a species combination is repeated a sufficient number of times can its failure be regarded as due definitely to lack of species crossability.

The approximate statistical reliability of the data on failures can be calculated in the following manner. If a total of $T$ tree x tree combinations of a crossable species combination are made, and $S$ tree x tree combinations of that species combination succeed, the probability that any one tree x tree combination will yield no viable seed is $(T\text{-}S)/T$. The probabilities are $(T\text{-}S)^2/T^2$, $(T\text{-}S)^3/T^3$, ..... $(T\text{-}S)^n/T^n$ that 2, 3, ....., n tree x tree combinations of that species combination will produce no viable seed.

There were sufficient data to permit the

*TABLE 5. Digest of species crosses in the 5-needled white pines by all agencies.*

| Parents[1] ♀ | ♂ | Success[2] and authority[3] | Parents ♀ | ♂ | Success and authority | Parents ♀ | ♂ | Success and authority |
|---|---|---|---|---|---|---|---|---|
| Ko | Ko | A–11 | La | St | F4,13 | Mo | La | F–4;U–15 |
| Ko | Al | U–13 | Ay | Ko | F–10 | Mo | Ay | H-4;U-15 |
| Ko | La | F–13 | Ay | Ce | F–10 | Mo | Pa | H–13 |
| Ko | St | F–13,14 | Ay | Fl | H–10 | Mo | Pe | H–6 |
| Ce | Ko | A–11 | Ay | Gr | H–10;U–4 | Mo | Gr | H–4,8;U–10 |
| Ce | Ce | F–11 | Ay | St | H–10 | Mo | Mo | H–5 |
| Al | Ko | F–4,13 | Pa | Ce | F–10 | Mo | St | H–4,6,8,13;U–10 |
| Al | Ce | F–4 | Pa | Fl | F–10,13 | Mo | PeSt | H–4 |
| Fl | Ko | F–10,13 | Pa | Pe | F–10,13 | St | Ko | F–9,10,13,14,16 |
| Fl | Ce | F–10 | Pa | Gr | F-10 | St | Ce | F–10,14 |
| Fl | Fl | H–10 | Pa | Mo | F–13 | St | Al | F–13 |
| Fl | Ar | U–4,10 | Pa | St | H–13;F–10,14 | St | Fl | H–10;F–9,13,14 |
| Fl | La | U–4 | Pe | Ko | F–10 | St | Ar | F-4,13,14 |
| Fl | Ay | A–15 | Pe | Ce | F–14 | St | La | F–4,13 |
| Fl | Gr | H–4,10 | Pe | Pa | H–13;F–10 | St | Ay | H–2,10;U–14 |
| Fl | St | F–4,10,13 | Pe | Pe | A-11 | St | Pa | H–3,9,10,16;U–14 |
| Re | Fl | F–13 | Pe | Gr | U-10 | St | Pe | H–2,13;F–10;U–14 |
| Ar | Ko | U–13 | Pe | St | H–10,14;U–13 | St | Gr | H–1,3,4,7,10,13,14 |
| Ar | Fl | U–4;F–13 | Gr | Ko | F–10 | St | Mo | H–13,14;U–4,10 |
| Ar | Re | F–13 | Gr | Ce | F–10 | St | St | H-9,10,11 |
| Ar | Ar | U–13 | Gr | Fl | U–4;F–10 | GrSt | Fl | A–15 |
| Ar | La | F–13 | Gr | Ar | F–10,A–15 | GrSt | Ar | A–15 |
| La | Ko | H–4 | Gr | La | F–4 | GrSt | Ay | A–15 |
| La | Al | F–4 | Gr | Ay | H–13;F–10 | GrSt | Pa | U–13 |
| La | Fl | F–13 | Gr | Pa | H–10 | GrSt | Gr | U–4 |
| La | Re | F–13 | Gr | Gr | H–10 | GrSt | Mo | U–4 |
| La | Ar | H–4,13 | Gr | Mo | U–4,15 | GrSt | St | H–13,15 |
| La | Ay | H–15;F–4 | Gr | St | H–1,10,13;U–4 | MoPa | GrSt | U–13 |
| La | Pa | F–4 | Gr | Ch | U–13 | MoGr | Fl | A–15 |
| La | Pe | F–4 | Mo | Ko | U–4,8 | MoSt | Ay | A–15 |
| La | Gr | F–4;A–14 | Mo | Fl | A–15 | MoSt | Gr | U–15 |
| La | Mo | F–4 | Mo | Ar | U–4;F–10;A–15 | | | |

[1]Species names are abreviated as follows: Ko = *P. koraiensis*; Ce = *P.cembra*; Al = *P. albicaulis*; Fl = *P. flexilis*; Re = *P. strobiformis* Englm. (= *P. reflexa* Englm.); Ar = *P. armandi*; La = *P. lambertiana*; Ay = *P. ayacahuite*; Pa = *P. parviflora*; Pe = *P. peuce*; Gr = *P. griffithii*; Mo = *P. monticola*; St. = *P. strobus*; Ch = *P. strobus* var. *chiapensis* Martinez.

[2]The success symbols are:

H = Hybrids produced and authenticated.
U = Undetermined. Full seeds produced but hybrids not yet authenticated.
F = Failure.
A = Attempted. Success not yet known.

[3]The authorities followed are:

1. Rehder, 1940.
2. Johnson and Heimburger, 1946.
3. Sax, 1947; Johnson, 1952.
4. Righter and Duffield, 1951.
5. Bingham, Squillace, and Duffield, 1953.
6. Riker and Patton, 1954.
7. Meyer, 1954.
8. Bingham, Squillace, and Patton, 1956.
9. NEFES, 1937-41, Unpub.
10. NEFES, 1947-56.
11. Ahlgren, C. E., personal communication.
12. Bingham, R. T., personal communication.
13. Johnson, A. G., personal communication.
14. Patton, R. F., personal communication.
15. Righter, F. I., personal communication.
16. Hyun, S. K., 1956.

*TABLE 6. Digest of white pine species crosses by all workers (Reciprocal crosses are shown as single combinations)*[1].

| Series and species | Series and species | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CEMBRAE | | | | FLEXILES | | | STROBI | | | | | | | | | |
| | koraiensis | pumila | cembra | albicaulis | flexilis | strobiformis | armandi | lambertiana | ayacahuite | parviflora | peuce | griffithii | monticola | strobus | formosana | | |
| **CEMBRAE** | | | | | | | | | | | | | | | | | |
| koraiensis | .... | | | | | | | | | | | | | | | | |
| pumila | .... | .... | | | | | | | | | | | | | | | |
| cembra | A[2] | .... | .... | | | | | | | | | | | | | | |
| albicaulis | F | .... | F | .... | | | | | | | | | | | | | |
| **FLEXILES** | | | | | | | | | | | | | | | | | |
| flexilis | F | .... | F | .... | .... | | | | | | | | | | | | |
| strobiformis | .... | .... | .... | .... | F | .... | | | | | | | | | | | |
| armandi | U | .... | .... | .... | U | F | .... | | | | | | | | | | |
| **STROBI** | | | | | | | | | | | | | | | | | |
| lambertiana | H | .... | .... | F | F | F | H | .... | | | | | | | | | |
| ayacahuite | F | .... | F | .... | H | .... | .... | H | .... | | | | | | | | |
| parviflora | .... | .... | F | .... | F | .... | .... | F | .... | .... | | | | | | | |
| peuce | F | .... | .... | .... | .... | .... | .... | F | .... | H | .... | | | | | | |
| griffithii | .... | .... | F | .... | H | .... | F | F | H | H | U | .... | | | | | |
| monticola | U | .... | .... | .... | A | .... | U | F | H | H | H | H | .... | | | | |
| strobus | F | .... | F | F | H | .... | F | F | H | H | H | H | H | .... | | | |
| formosana | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | | |
| strobus var. chiapensis | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | U | .... | .... | .... | .... | |

[1]Compiled from Table 5.

[2]The symbols are: H = Hybrids produced and authenticated. U = Undetermined. Full seeds produced but hybrids not yet authenticated. F = Failure. A = Attempted; success not yet known.

calculation of these probabilities for five female parent species. The probabilities are presented in Table 7, which is based on data from the most successful type of pollination treatment (fresh pollen, sausage-casing bags) in the following successful species x species combinations: *P. flexilis* x *griffithii*, *P. ayacahuite* x *griffithii*, *P. ayacahuite* x *strobus*, *P. peuce* x *strobus*, *P. griffithii* x *griffithii*, *P. griffithii*, x *strobus*, *P. strobus* x *ayacahuite*, *P. strobus* x *parviflora*, *P. strobus* x *griffithii*, *and P. strobus* x *strobus*. In order to eliminate the few tree x tree combinations whose success might have been due to contaminating pollen, only those tree x tree combinations yielding 1.0 or more filled seed per cone were considered as successful in making the calculations.

It is evident from Table 7 that species crossing work in the white pines should be done on a large scale if it is to give determinate results.

*Nursery performance of the hybrids.* The crosses *P. parviflora* x *cembra*, *P. parviflora* x *flexilis*, *P. parviflora* x *strobus*, *P. griffithii* x *flexilis*, and *P. strobus* x *koraiensis* resulted in very small numbers of presumably filled seeds that did not germinate or gave seedlings indistinguishable from the female parent. Therefore, these crosses are presumed to be failures.

The crosses *P. flexilis* x *armandi*, *P. peuce* x *griffithii*, *P. monticola* x *aya-*

*chahuite*, *P. monticola* x *griffithii*, and *P. monticola* x *strobus* resulted in moderate to large numbers of filled seeds. Their seeds have not yet been sown in the nursery, but these crosses are regarded as probably successful.

The remainder of the successful species combinations (Table 3) have been grown in the nursery and a few have been outplanted. The identity of each seedlot was confirmed by comparing the hybrids with seedlings of one or both parent species. Most of the truly diagnostic characteristics did not develop until the trees were 3 or 4 years old. Following is an annotated list of the authenticated species combinations. The female parent in each case is listed first.

*P. flexilis* x *griffithii*.—Higher germination percent, longer and more serrate needles, and greater 3-year height than *P. flexilis*. Bluer and less serrate needles, and greater 3-year height than *P. griffithii*. This combination appears to have considerable growth promise.

*P. ayacahuite* x *flexilis*.—Shorter and less serrate needles and 50 percent less 3-year height than *P. ayacahuite* x *strobus*. More serrate needles than *P. flexilis*; similar in height to *P. flexilis*.

*P. ayacahuite* x *griffithii*.—Longer needles, more closely appressed bud scales, and similar 3-year height to *P. ayacahuite* x *strobus*.

*P. ayacahcite* x *strobus*.—Longer and bluer needles, more Lammas shoots, and greater 4-year height and diameter than *P. strobus*. Similar in growth rate and general appearance to the reciprocal hybrids.

No *P. ayacahuite* seedlings were available to serve as controls. The authenticity of the supposed hybrids is considered certain because of the consistently high seed sets, the near impossibility of self-or cross pollination by *P. ayacahuite* in some years, and the similar appearance of seedlots of the same species combination sown in successive years.

The oldest *P. ayacahuite* x *strobus* hybrids were field-planted at Williamstown, Mass. and Villanova, Pa. in 1952. The Williamstown trees have suffered higher mortality and have grown much more slowly than *P. strobus* planted at the same time; October 1955 (8-year) average heights were 63 and 124 centimeters for the hybrids and *P. strobus*, respectively. The hybrids planted at Villanova have grown about as fast in height and slightly faster in diameter than *P. strobus*.

The *P. ayacahuite* tree used as a female parent has coarser branches than *P. strobus* and appears to transmit this characteristic to the progeny. If finer-branched parents were located, this combination and its reciprocal would appear promising for the more southerly parts of the Northeast.

*P. peuce* x *strobus*.—slower growing than *P. strobus* in the nursery and during the first 4 years after outplanting at Williamstown, Mass. No *P. peuce* seedlings were available to serve as controls. The authenticity of the supposed hybrids is considered reasonably certain because of the consistency of seed sets,

*TABLE 7. Probability of obtaining no filled seeds from varying numbers of tree x tree combinations between crossable species*[1].

| Female parent *Pinus*— | Number of tree x tree combinations attempted | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| | Probability | | | | | | | |
| *flexilis* | 0.2080 | 0.0432 | 0.0090 | 0.0019 | 0.0004 | 0.0001 | 0.0000 | 0.0000 |
| *ayacahuite* | .2000 | .0400 | .0080 | .0016 | .0003 | .0001 | .0000 | .0000 |
| *peuce* | .3333 | .1113 | .0370 | .0124 | .0041 | .0014 | .0005 | .0002 |
| *griffithii* | .6000 | .3600 | .2160 | .1296 | .0776 | .0465 | .0280 | .0168 |
| *strobus* | .6879 | .4725 | .3240 | .2230 | .1531 | .1050 | .0721 | .0497 |

[1]The calculations were based on totals of 24, 10, 12, 65, and 141 tree x tree combinations in *P. flexilis*, *P. ayacahuite*, *P. peuce*, *P. griffithii*, and *P. strobus* respectively. Averages of 51.6, 13.0, 21.1, 32.5, and 21.8 female flowers were devoted to each tree x tree combination in these five female parent species respectively.

*TABLE 8. Four-year heights of hybrid and non-hybrid white pine progenies grown in the Philadelphia experimental nursery.*

| Female x male parents *pinus*— | Tree x tree combinations | Seedlings measured | Average height |
|---|---|---|---|
| | *Number* | *Number* | *Centimeters* |
| | 1948 SEED CROP | | |
| *strobus* x *strobus* | 4 | 28 | 48.2 |
| *strobus* x *flexilis* | 1 | 4 | 38.4 |
| *flexilis* x *flexilis* | 1 | 2 | 24.1 |
| | 1950 SEED CROP | | |
| *strobus* x *strobus* | 7 | 29 | 39.4 |
| *strobus* x *griffithii* | 8 | 122 | 51.4 |
| *griffithii* x *strobus* | 1 | 2 | 51.4 |
| *strobus* x *ayacahuite* | 5 | 62 | 44.0 |
| *griffithii* x *griffithii* | 1 | 10 | 34.3 |

the near impossibility of pollination by *P. peuce* in most years, and the hybrid's similarity to *P. strobus*.

*P. griffithii* x *parviflora*.—Four-year-old seedlings intermediate in needle length and height growth. This combination shows little promise because of slow growth.

*P. griffithii* x *strobus*.—Greater 4-year height than either parent (Table 8). This combination and its reciprocal show considerable promise because of rapid growth and possible rust resistance.

*P. strobus* x *flexilis*.—Bluer and less serrate leaves, and less 4-year height than *P. strobus* (Table 8). The particularly slow growth of the few trees obtained from this combination may be due to the male parent, one of the poorest *P. flexilis* specimens in the Philadelphia area.

*P. strobus* x *parviflora*.—Shorter needles, less 4-year height, and lower germination percent than *P. strobus*. The germination percentages of the hybrid and non-hybrid seeds were 9 and 97 percent, respectively; Chi-square analyses showed the difference to be significant at the 1 percent level. Johnson (1952) reported that natural hybrids of this combination (*P.* x *hunnewelli* A. G. Johnson) were probably heterotic but of poor timber form.

*P. strobus* x *griffithii*.—Longer needles, more closely appressed bud scales, larger diameter leaders, and greater 4-year height than *P. strobus* (Table 8).

*P. strobus* x *ayacahuite*.—Longer needles, browner buds, higher percentage of trees with Lammas shoots and bent needles, and greater 4- year height than *P. strobus* (Table 8).

### Mass-Production Possibilities

The potential value of the $F_1$ species hybrids depends not only on their performance but also on the ease with which they may be mass-produced by seed. The following tabulation gives the seed yields of the most productive tree x tree combinations in the nine most productive species combinations.

| *Female x male parent, Pinus* | *Full seeds per cone (number)* |
|---|---|
| *flexilis* x *griffithii* | 22.0 |
| *peuce* x *strobus* | 9.5 |
| *griffithii* x *strobus* | 9.3 |
| *monticola* x *griffithii* | 25.2 |
| *monticola* x *strobus* | 16.2 |
| *ayacahuite* x *griffithii* | 24.3 |
| *ayacahuite* x *strobus* | 21.2 |
| *strobus* x *griffithii* | 6.2 |
| *strobus* x *ayacahuite* | 13.0 |

All these species combinations except *P. peuce* x *strobus* have shown possible hybrid vigor when tested in the Northeast or in California (Righter and Duffield 1951).

A few semi-controlled pollinations (female flowers pollinated but not bagged) were made on young, isolated, Philadelphia trees that produced no pollen. This was

done to test the feasibility of mass-producing $F_1$ seed in natural crossing gardens. Results of the five most fruitful tree x tree combinations are shown in the following tabulation.

| *Female x male parent, Pinus—* | *Good Seeds per cone following pollination by—* Wind | Wind and applied pollen |
|---|---|---|
| *peuce* x *strobus* | 1.1 | 3.9 |
| *monticola* x *strobus* | .0 | 18.7 |
| *strobus* x *griffithii* | .7 | 5.5 |
| *strobus* x *griffithii* | .1 | 4.6 |
| *strobus* x *griffithii* | .0 | 6.2 |

Similar semi-controlled pollinations on partially isolated limber and Himalayan white pines resulted in no appreciable set of hybrid seed.

The single, isolated (by more than 40 miles) specimen of Mexican white pine used as a female parent yielded an estimated 7,000 and 20,000 filled seeds to wind pollination in 1950 and 1955, respectively. The proximity of large pollinating eastern white pines, the comparative seed sets after wind and controlled pollination, and the nursery performance of the progeny indicate that most or all of these seeds were actually *P. ayacahuite* x *strobus*.

These preliminary results indicate that mass-production of $F_1$ seed by bagging plus hand pollination, by hand pollination of unbagged "female" trees, or by wind pollination of "female" trees may be an economic possibility in certain species combinations—particularly those involving Mexican white pine and western white pine as female parents. Much more research is necessary before eastern white pine can be used successfully as a female parent for the mass-production of species hybrids.

## Summary

The results of 10 years' work on species hybridization with the 5-needled pines at the Northeastern Forest Experiment Station are summarized. Including reciprocals, 38 different species combinations were attempted, of which 16 are regarded as successful or probably successful. Twelve of the 16 combinations have been authenticated in the nursery.

Comparative trials were made of year-old pollen stored in a refrigerator or deep freeze and fresh pollen of the same species. In nearly all cases, total (filled plus empty) seed sets were similar for the two types of pollination; but sets of filled seeds were higher (appreciably so in three cases) after the use of fresh pollen than after the use of year-old pollen.

The combinations *P. flexilis* x *griffithii*, *P. griffithii* x *strobus*, *P. ayacahuite* x *griffithii*, *P. ayacahuite* x *strobus*, *P. strobus* x *griffithii*, and *P. strobus* x *ayacahuite* are among the most promising. They gave maximum seed yields of 22.0, 9.3, 24.3, 21.2, 6.2, and 13.0 filled seeds per cone, respectively, and grew faster than seedlings of either parent species in the nursery.

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## Environmental Conservation

*By Raymond F. Dasmann. 307pp. Illus. John Wiley and Sons, Inc., New York. 1959. $6.50.*

*Review by Grant W. Sharpe*
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Professor Dasmann defines conservation as "the use of natural resources to provide the highest quality of living for mankind . . . aiming toward both a material and a spiritual enrichment of life for man on earth, now and in the future." His treatment of this subject, so rich in opportunities for digression, is orderly, and the illustrations are both interesting and significant. The varied aspects of biotic communities are presented in a manner that is clearly understandable and yet which stimulates the reader to further investigation.

As a native of Washington, this reviewer does not mind if Professor Dasmann gives credit to that state for still maintaining the lead in lumber production, but Oregonians may object.

The well-presented case for the need to maintain climax habitat conditions to preserve the caribou and the fur-bearers will give aid and comfort to the proponents of wilderness area legislation. He offers further convincing reasons for the preservation of wilderness areas of all biotic types, and when presented as a part of a highly integrated conservation program, there is little left for opponents to argue. This same logical spirit prevails in the chapter on Land and Wild Animal Life, and should be required reading for uninformed "conservationists," as well as those hunters who would assure success through overpopulation.

The closing chapters, on the problems of population, are refreshingly free from prejudice and propaganda for one viewpoint or another that so often pervades writings on this subject.

Until recently most work is conservation was done in a specialized, isolated manner. Professor Dasmann looks to education to bring about a more concerted approach. Yet in his lucid explanation of their interdependence the author does not allow the many aspects of conservation to merge in an amorphous and boring generality. One puts the book down with new ideas, fresh outlooks, and perhaps even the first stirrings of an "ecological conscience." It may be hoped then that it will enjoy the wide audience it could so profitably serve.

# *Rate of Decay in Northern Hardwoods Following Artificial Inoculation with Some Common Heartrot Fungi*

BY
SAVEL B. SILVERBORG

RELATIVELY LITTLE IS KNOWN concerning the rate of decay in standing timber following initial infection by heartrot fungi. In order to measure decay rate in living trees it is necessary to know the time of infection, and this can be determined accurately by artificial inoculation.

Early investigators estimated the rate of wood decay in standing trees that were naturally infected. The time of initial infection, therefore, was not definitely established. Münch (1915) in a study of heartrot in oak by *Fomes igniarius* (L. ex Fries) Kickx. found the average yearly rate of decay in vertical direction to be 0.16 to 0.30 feet. There was no significant difference in the upward and downward rate of spread from the point of infection. Boyce (1920) found the average yearly rate of decay by *Polyporus amarus* Hedgc. in incense cedar to vary from a minimum range of 0.01 to 0.20 feet and a maximum range from 0.01 to 0.35 feet, although the rate could be much faster or slower in individual trees. Hepting (1935) in a study of decay in young Mississippi Delta hardwoods resulting from fire scars found the average yearly rate of decay to be 0.19 feet for oaks and somewhat less for the other species.

To determine the rate of decay in standing timber following artificial inoculation Hirt and Eliason (1938) found that ten years after *Fomes pinicola* (Swartz ex Fries) Cke. was introduced into living trees the maximum vertical extent of decay was 7.9 feet in red spruce and 3.5 feet in yellow birch. Hirt (1949) found, as a result of a 10-year study of northern hardwoods artificially inoculated with some common heartrot fungi, that a *Fomes igniarius* isolate from aspen caused a yearly average rate of decay of 0.7 feet in aspen and 1.1 feet in yellow birch. In this same study a *Poria obliqua* (Pers. ex Fries) Karst. isolate from a sterile conk on yellow birch caused a yearly average rate of 2.50 feet of decay in aspen and 2.36 feet in yellow birch.

In 1951 a 15-year study was started at the State University College of Forestry, Huntington Wildlife Forest, Newcomb, New York to determine the rate of decay in northern hardwoods following artificial inoculation with some common heartrot fungi. The information presented in this paper summarizes the results at the end of 5 years.

## Materials and Methods

*Hosts and fungi.* Four species of hardwoods, sugar maple (*Acer saccharum*

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Marsh.), yellow birch (*Betula alleghaniensis* Britton), American beech (*Fagus grandifolia* Ehrh.), and bigtooth aspen (*Populus grandidendata* Michx.) were inoculated artificially with pure cultures of common heartrot fungi as listed in Table 1.

The isolates of *Fomes igniarius* from bigtooth aspen, sugar maple and American beech and the isolate of *Fomes applanatus* (Pers. ex Fries) Gill. from American beech were obtained from the context tissue of actively growing sporophores. The isolates of *Polyporus glomeratus* Peck were obtained from sterile conks collected from sugar maple and American beech and the isolate of *Poria obliqua* from a sterile conk growing on yellow birch. In each instance the fungi were artificially introduced into the same tree species from which the cultures were originally obtained.

*Preparation of inoculum.* The method of growing the fungus inoculum was similar to that used by Darley and Christensen (1943) in studying sporophore formation in *Trametes suaveolens* (L. ex Fries) Fries. A ½-inch diameter hole was drilled through basswood dowels to within ½-inch of the end. Dowels were 3 inches long and ⅝-inch in diameter. The holes were loosely packed with a mixture of equal parts of oats and barley which had been previously soaked in distilled water for four hours. The dowels with the drilled ends up were placed in 8-ounce French square bottles which had a one-half inch layer of moist absorbent cotton in the bottom (Fig. 1) and autoclaved for one-half hour at 121°C. After the bottles had cooled to room temperature a one-fourth inch malt agar disk of pure cultures of the various fungi was placed on the surface of the oat-barley mixture. The inoculum plugs were then incubated for five weeks at room temperature. At the end of this period the fungous mycelium had grown throughout the oat-

*TABLE 1. Mean vertical extent of decay, average yearly extent, and percent of cross-sectional area decayed at the point of inoculation in four northern hardwoods five years after artificial inoculation with common heartrot fungi.*

| Fungus, host and source[1] | Mean vertical extent of decay in feet[2] | | Average yearly extent in feet | Decay at point of inoculation in percent of cross-sectional area |
|---|---|---|---|---|
| | Down | Up | | |
| *Fomes igniarius* in bigtooth aspen | 3.6 (3.3-4.0) | 5.9 (5.5-6.6) | 1.90 | 58.3 |
| *Fomes applanatus* in American beech | 2.6 (1.6-3.5) | 3.0 (2.4-3.5) | 1.12 | 57.0 |
| *Fomes igniarius* in American beech | 2.4 (1.6-2.8) | 2.4 (1.3-3.3) | 0.96 | 22.2 |
| *Polyporus glomeratus* in sugar maple | 1.4 (1.3-1.6) | 1.4 (1.3-1.6) | 0.56 | 45.5 |
| *Polyporus glomeratus* in American beech | 0.4 (0.2-0.5) | 0.6 (0.2-0.8) | 0.20 | 13.1 |
| *Poria obliqua* in yellow birch | 0.3 (0.1-0.4) | 0.4 (0.1-0.6) | 0.14 | 12.6 |
| *Fomes igniarius* in sugar maple | 0.3 (0.1-0.4) | 0.3 (0.1-0.5) | 0.12 | 13.3 |

[1]Scientific names of the hosts appear in the text and the sources of fungal inoculum are from the same host into which inoculations were made.

[2]Means are based on 5 trees; ranges are included in parentheses.

barley mixture and had nearly covered the surface of the dowels (Fig. 1).

*Field inoculations.* Trees selected for inoculation were in the dominant and co-dominant crown classes, 8 to 12 inches d.b.h. and 80 to 100 years old. Every effort was made to select trees that were free of visible outward defects. The wooden chips from the borings for the inoculum plugs were examined for decay and only sound trees were selected. Inoculations were made at 5 feet above the ground on the south quadrant of each tree. Approximately a 4-inch square of bark surface was smoothed with a bark scraper and sterilized with 70 percent ethyl alcohol. In the middle of this sterilized area a hole ¼-inch in diameter was drilled to the center of the tree with a sterilized auger at a slight upward angle. A dowel containing the actively growing fungus was then aseptically inserted into the hole and forced to its maximum depth. A second 3-inch surface-sterilized dowel was driven in the hole to prevent outside contamination. A total of 105 inoculations were made during June and July of 1952, 15 trees for each fungus on the tree species listed in Table 1. In addition, six control dowels containing only the sterile oat-barley mixture were used in each of the four tree species. At the end of five years, one-third of the total number of trees inoculated were felled and the extent of decay measured. Similar data will be collected and presented at the end of ten years and 15 years.

## Results

*Rate of decay.* The results of the inoculations are summarized in Table 1.

*Fomes igniarius* in bigtooth aspen resulted in the greatest vertical development of decay and also the greatest percent of cross-sectional area[1] decay at the point in infection, 9.5 feet and 58.3 percent respectively, a yearly average of 1.9 feet of vertical decay. The cross-sectional area of decay was determined by measuring the average diameter of decay at the point of artificial inoculation. *F. igniarius* on beech averaged 4.8 feet of vertical decay or a yearly average of 0.96 feet. The decay at the point of infection was only 22.2 percent of cross-sectional area. *F. igniarius* in sugar maple caused only limited decay.

*Fomes applanatus* inoculated into American beech ranked next to *F. igniarius* on bigtooth aspen both in vertical extent of decay and also percent of decay in cross-section, 5.6 feet and 57.0 percent respec-

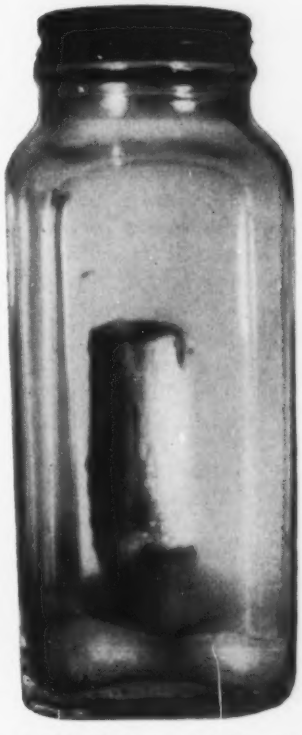

FIGURE 1. *Mycelial growth of* Fomes igniarius *on surface of hollow wooden dowel filled with an oat-barley mixture used for artificial inoculations.*

[1]Per cent of cross-sectional area decay $= \frac{\text{(decayed cross-sectional area)}}{\text{(total cross-sectional area)}} \times \frac{100}{1}$

tively, or a yearly average of 1.12 feet of vertical decay.

Sugar maple inoculated with *Polyporus glomeratus* caused the greatest amount of decay among the sterile conk fungi. The vertical extent of decay was 2.8 feet, a yearly average of 0.56 feet, and 45.5 percent of cross-sectional decay. *Poria obliqua* and *Polyporus glomeratus*, the other two sterile conk fungi in yellow birch and American beech respectively, caused only limited decay (Table 1).

Isolations were made from the decayed wood to determine whether the fungus causing the decay was the same as that originally introduced into the trees. In each instance they were identical. Although discoloration occurred around the control dowels no decay was present. The vertical extent of decay upward and downward from the point of inoculation was essentially the same wtih the exception of *Fomes igniarius* in bigtooth aspen. In this case the upward extent of decay was significantly greater than the downward extent of decay.

*Canker development.* In American beech inoculated with *Fomes igniarius* the sapwood was decayed, in addition to heartwood, resulting in sunken cankers at the point of inoculation (Figs. 2 and 3A). The cankers were first observed as slightly sunken, dead areas on the bark three years after inoculation. No cankers developed in bigtooth aspen or sugar maple inoculated with *F. igniarius* (Fig. 3B).

*Fomes applanatus* inoculated in American beech also developed pronounced sunken cankers at this point of inoculation (Fig. 4). This is to be expected since *F. applanatus* normally causes decay of both the heartwood and sapwood of living trees. The cankers first became visible three years after inoculation.

*Polyporus glomeratus* in sugar maple, the only sterile conk fungus that caused any appreciable amount of decay, had not produced cankers at the end of five years. The decay was limited to a relatively small core of the inner heartwood. In older infections, however, this fungus has been observed to cause cankers on both sugar maple and American beech (Silverborg 1954).

FIGURE 2. *One-year old sporophores of* Fomes igniarius *on American beech five years after artificial inoculation. Sunken canker around the point of infection was caused by decay of the sapwood by* Fomes igniarius.

*Sporophore formation.* The length of time required for sporophores to develop after a fungus becomes established in living trees can be determined accurately only by artificial inoculations. Hirt (1949) reported the development of sporophores of *Fomes igniarius* on eastern hophornbeam (*Ostrya virginiana* (Mill.) K. Koch) in six years and on aspen in ten years after artificial inoculation.

In the present study sporophores were produced on bigtooth aspen and American beech (Fig. 2) inoculated with *Fomes igniarius*. They first appeared as slightly raised masses of fungous tissue four years after inoculation, and at the end of the following year, or five years after inoculation, a layer of tubes had formed.

In American beech the sporophores

formed on the sunken, cankered area around the dowel where the fungus had decayed the underlying sapwood (Fig. 2). In bigtooth aspen the outer sapwood was undecayed (Fig. 3B) but the fungus had grown outward through the dowel and the sporophores developed around the base and on the surface of the exposed portion of the dowel.

The time of initial sporophore formation is an important factor in the proper management of American beech. Because of its heavy cull, much of which is due to heartrot caused by *F. igniarius*, American beech is considered by many foresters to be an undesirable species. Since heartrot losses are apparently relatively minor in this species when sporophores of *F. igniarius* first appear, more merchantable volume can be expected if trees are harvested soon after the conks first become visible. In contrast, volume losses in bigtooth aspen are extensive when fruiting bodies of *F. igniarius* first become visible.

FIGURE 4. *Canker on American beech formed five years after artificial inoculation with* Fomes applanatus.

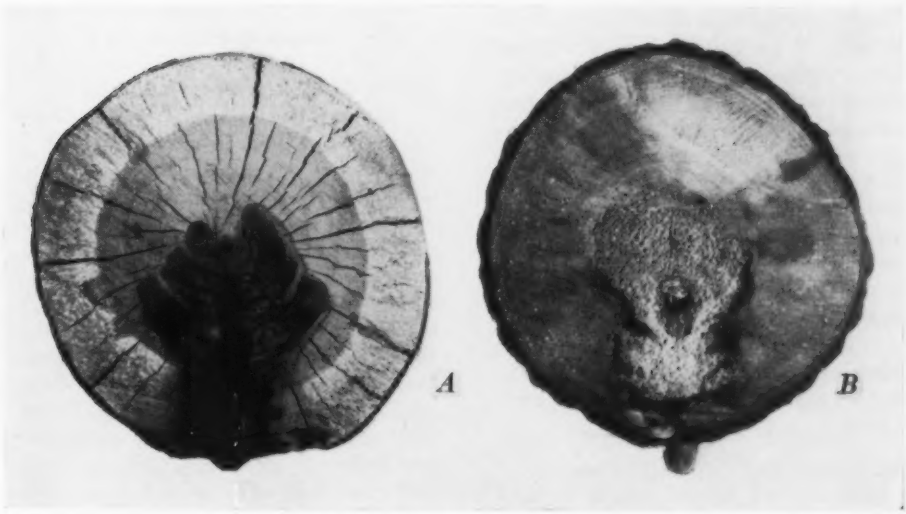


FIGURE 3. *Cross-section of American beech (A) and bigtooth aspen (B) showing decay due to* Fomes igniarius *immediately above the point of inoculation.*

### Summary

The results of a five-year study on the rate of decay, canker development and sporophore formation in four northern hardwood species following artificial inoculation with some common heart-rot fungi are summarized as follows:

1. *Fomes igniarius* in bigtooth aspen caused the greatest amount of vertical decay, 9.5 feet, in five years. In decreasing order the other fungi causing extensive decay were *F. applanatus* in beech (5.6 feet), *F. igniarius* in beech (4.8 feet), and *Polyporus glomeratus* in sugar maple (2.8 feet).

2. *F. igniarius* in sugar maple, *Poria obliqua* in yellow birch and *Polyporus glomeratus* in American beech caused only limited decay.

3. Cankers were formed on American beech by both *F. igniarius* and *F. applanatus* three years after inoculation.

4. Abortive sporophores of *F. igniarius* first appeared on bigtooth aspen and American beech four years after inoculation. The following year a single layer of tubes had formed.

5. Young sporophores of *F. igniarius* on American beech indicate only limited decay. On bigtooth aspen, however, decay caused by *F. igniarius* is extensive when the conks first become visible.


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# *Winter Changes in Tree Radii And Temperature*

BY
JOHN A. SMALL
CARL D. MONK

WHILE MEASURING radial growth of trees throughout the year, it became apparent that during the dormant winter period there was considerable fluctuation in radial readings with the dial gauge dendrometer. Markedly lower readings were rather consistently recorded on those days when the temperature was noticeably low, i.e. below 32° F.

Marvin (1949) has studied such changes in sugar maple. Fritts and Fritts (1955) recorded similar changes in beech. Byram and Doolittle (1950) recorded 0.3 mm contractions and expansions in shortleaf pine during a January cold spell in North Carolina. Friesner and Walden (1946) observed shrinkages of more than 1.0 mm in white pine in Maine during the winter.

As a further contribution, two white ash trees (*Fraxinus americana* L.), located in a lawn at Franklin Park, N. J., were chosen for intensive study. Stations for operating an Ames 262 shockless dial gauge mounted as described by Daubenmire (1945) were established on radii at the eight major compass points, at the four-foot height on each tree. Readings were made to the nearest 0.001 inch since fluctuations were so great as to make more refined interpolation unjustified. Each station consisted of three 2-inch. No. 8, round-head brass wood screws. The dial gauge was mounted on an oak block with a brass plate against which the screws seated when the dendrometer was applied to the station. The question of thermal linear expansion changes in length of screws and in the plunger on the dial gauge was considered. The fluctuations in readings were great enough and of such character that they were obviously associated with the tree rather than the instrument.

An attempt to mount mercurial, laboratory type thermometers (Fisher Scientific Company #14-990) so that the bulb would be against the bark adjacent to the plunger contact point proved impracticable. Obviously the sun influences bark temperatures on those radii receiving direct insolation to a greater extent than it influences the temperature on the more sheltered radii. Since studies during the growing season had indicated great differences in the growth response of the several radii, it seemed more adequate to average the radial changes at the 16 stations and take one temperature reading. A bimetalic, dial thermometer that was fully exposed but shaded was employed to measure the temperature. It remained in the same position throughout the experiment.

Readings were taken at approximately three hour intervals at all stations for a six

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day period (December 26, 1955 to January 1, 1956). All readings were made by the senior author. The temperature varied from 8° F to 41° F during the course of the study. The daily records fluctuated above and below 32° F with the exception of one day when for a 24-hour period the temperature remained between 32° F and 25° F. This period was ideal for testing the hypothesis that radial change is closely correlated with fluctuation of temperature in the freezing range.

### Results

The daily march of temperature and the radial changes at each station appear in Figure 1. Fluctuations in the sixteen radii were not of the same magnitude. The east, southeast, south, southwest, and west sides exhibited a slightly greater increase during the day and a greater decrease during the night. These data imply strongly that there is some correlation between radial change in the dormant winter period and temperature change within the range studied.

When the change at the sixteen radii of the two trees were averaged and plotted with temperature (Fig. 1) there likewise appeared to be a close correlation. Each day the highest temperature came during the noon hour or shortly thereafter. Correspondingly, the major radial increase came during the same hour. The lowest temperatures generally were recorded at 6:30 am. This usually represented the peak of radial contraction (Fig. 2). From 3:30 pm on December 29 to 3:30 pm on December 30 the temperature fluctuated between 32° F and 25° F. During this same period the average radial fluctuation was between +0.001 and −0.001 inches. The radial measurements were more stable during this period than during others.

With only a few exceptions the peaks and valleys of the two curves coincide. These exceptions were expected since the actual maxima and minima probably occurred some minutes before or after the readings thus creating a recorded lag. When summation of average radial change is plotted with temperature (Fig. 2) the correlation between the two is better than when temperature is compared with the average radial change (Fig. 1). This seems to suggest that the summation of average radial change is more representative of what is happening than is average change, i.e. the summation represents the total effect while the average change represents the change since the last reading.

The individual radius and the average of the eight radii in Figure 1 illustrate an interesting point. Each radius responded similarly under the same temperature regimes regardless of exposure. Nearly all of the major peaks coincide as well as numerous minor ones. A comparison of each radius and the average of the eight radii with temperature show that an average is justifiable even though the north side was not subjected to direct insolation. Also, the accuracy of the dial gauge dendrometer for spot readings is well illustrated since each radius exhibited the same trends under similar temperature regimes.

To test our hypothesis and our visual analysis of the graphs, the data were treated by regression analysis as outlined by Moroney (1951) to see whether there was a linear relationship between temperature change and average radial fluctuation. The following formula ($y = b_o + b_1$, with $b_o = -10.377$ and $b_1 = +0.437$) was used to calculate, by the method of least squares, the line of best fit (Fig. 3). The correlation ($r = 0.75$) of average radial change and air temperature is significant at the one percent level ($t = 12.25$, d.f. $= 96$).

### Discussion

It should be pointed out that the relationship between radial change with temperature change below freezing is not as simple as is illustrated in Figures 1-3. When the temperature drops from 22° F to 20° F the response is not necessarily of the same magnitude as when the temperature drops

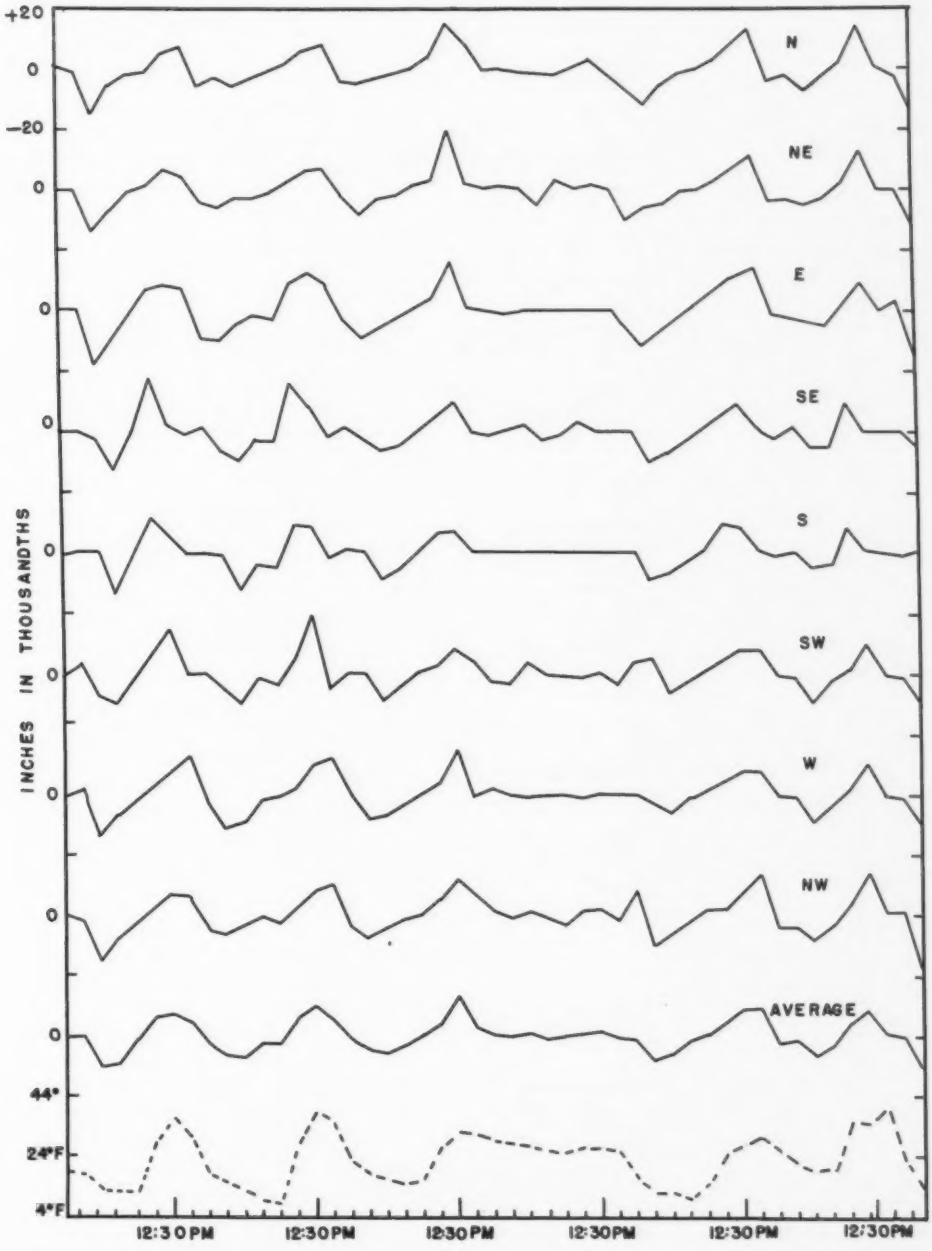


FIGURE 1. *Radial change and the average radial change for one white ash tree from December 26, 1955 to January 1, 1956 plotted with the temperature regime at the time of radial measurement.*

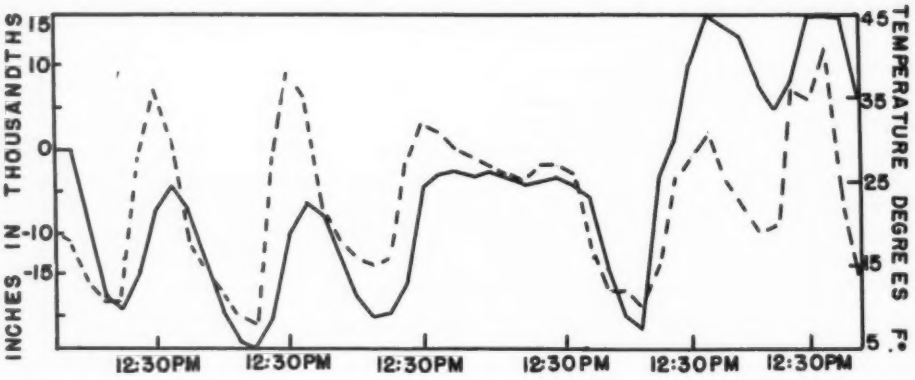


FIGURE 2. *The summation of average radial change in two white ash trees plotted with air temperature. Each point represents the average of 16 measurements from two trees at a four-foot height.*

from 16° F to 14° F. The same holds true for an increase in temperature. Another important factor is time. The trees may be subjected to the same temperature level twice but may respond differently due to the length of exposure.

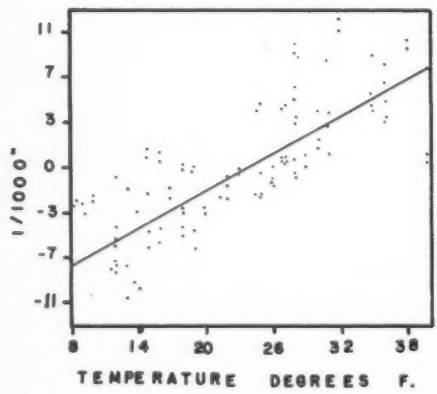


FIGURE 3. *The relation of average radius of white ash to air temperature during the period December 26, 1955 to January 1, 1956. Each point represents the average of 16 measurements from two trees at a four-foot height.*

The findings of this study are in close agreement with those of Fritts and Fritts (1955) who found that contractions in beech were more pronounced with temperatures below 25° F. Our study shows a direct relationship between temperature change below 32° F and the contraction and expansion of the average radius of two white ash trees (Fig. 3). The point the regression line crosses the zero axis (24° F) gives the temperature at which time radial contraction commences.

We have no data to identify the area in cross section of the stem which may be responsible for these radial fluctuations. Wiegand (1906) has shown that changes in bark are more pronounced during freezing temperatures. He noted an external wrinkling of twigs, and calculated that bark contracted 13.5 percent and wood only 2.5 percent. Marvin (1949) has made careful studies of radial change in sugar maple and he showed that bark contracted and expanded more with changes in temperature than did the xylem. Byram and Doolittle (1950), working with shortleaf pine, offered three possible explanations of radial contraction and expansion with temperature fluctuation below freezing: (1) the free

water is translocated to some other part of the tree, probably the root system, (2) a reversible change of free water to bound water with low temperatures, and (3) continued transpiration with inhibition of roots to absorb water.

The physiological changes accompanying freezing temperatures have been reviewed by Levitt (1941). He pointed out in his review that freezing . . . "in the intercellular space is accompanied by shrinkage of the whole cell wall" . . . which is a result of exosmosis from the cell to intercellular spaces. A reduction of turgor pressure would result from exosmosis producing an effect of overall contraction. This seems to be a better explanation. The bark, because of its structure as well as its position, would then be an "odds-on" choice as the area of most of the change in these radial fluctuations.


### Summary

1. Radial changes were recorded on the eight major compass bearings in two white ash trees for a six day period during which time air temperature fluctuated above and below freezing. 2. The average radial change (of 16) plotted against time was remarkably similar to the air temperature change so plotted. 3. Statistical analysis showed a significant correlation between average radius and air temperature changes. 4. The radial change was interpreted as a physiological phenomenon of exosmosis resulting from freezing in the intercellular spaces which produces an overall contraction in tree radius.


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# *A Comparison of the Gunn-Bellani Radiation Integrator and the Eppley Pyrheliometer*

BY
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THE EPPLEY pyrheliometer is the standard instrument used for solar radiation intensity measurements in the United States. However, this instrument, with recorder, is expensive and requires a source of electrical power. In certain experiments it is desirable and necessary to measure radiation in the forest or field. If different stand or light conditions are investigated several instruments are required. A portable, relatively low-cost instrument requiring no electrical power or battery power is needed in the field.

Certain types of instruments used for light intensity measurements in forest work in Scotland are discussed by Conners (1958) and by Fairbairn (1958). The Gunn-Bellani radiation integrator (Baird and Tatlock, 1958) is also a possible instrument for this purpose. It is a liquid distillation instrument consisting of an outer cylinder in which the radiation integrator is placed (Fig. 1). The cylinder 6 inches in diameter and 26 inches long is constructed of iron sheeting which provides relatively cool conditions and standardized ventilation for the condenser. This is placed in the soil. The radiation integrator consists of a blackened copper bulb, which serves as the water reservoir, inside a glass jacket, plus a condenser and a burette. The black bulb absorbs energy and water is evaporated. The vapor is condensed and collected in the burette. After a period in the field a reading is taken of the amount of water in the burette. The instrument is inverted to return most of the water to the copper sphere and the burette read again to obtain a reading of the water volume still in the burette. This serves as the zero reading for the next period of observation. The integrator is placed in the cylinder with the top of the glass jacket projecting ½ inch above the ground so that no radiation reflected from the ground is received.

Three of these instruments were located side by side in the Iowa State Forest Nursery south of Ames, and approximately hourly readings were obtained during part of the daylight hours for a period of 9 days under a wide range of radiation. These readings were related to those for identical time periods from the Eppley pyrheliometer which was located on top of the Agronomy Building about 3 miles from the nursery. The data for the individual integrators were tested statistically and found not to differ

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significantly. They were then combined into one set of data from which the linear regression

$$\hat{Y} = 9.96 + 20.92\ x,\ r = 0.93^{**}$$

was computed. The relationship is shown in Figure 2. It should be noted that 16 of the 20 points with evaporation below .025 ml fell below the regression line. This could well indicate that this portion of the curve is not linear. However, it can also be seen that zero evaporation is reached before zero solar radiation is reached. Zero evaporation occurs somewhere between 0 and 10 gm cal/cm²/hr solar radiation. The

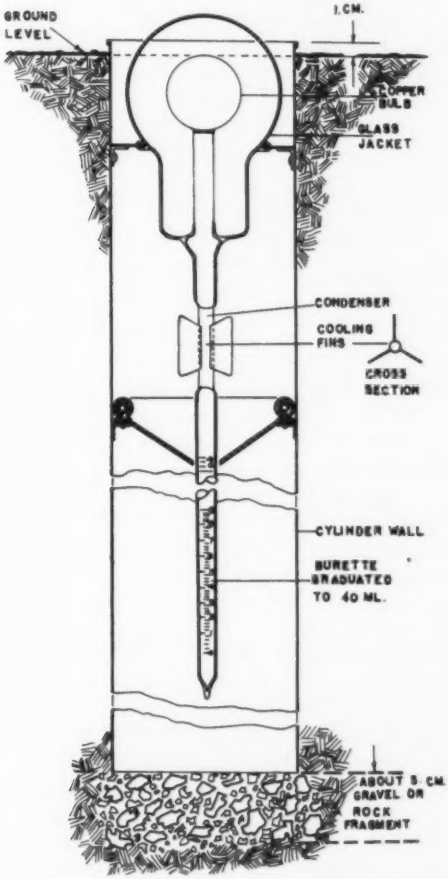


FIGURE 1. *Sketch of Gunn-Bellani radiation integrator.*

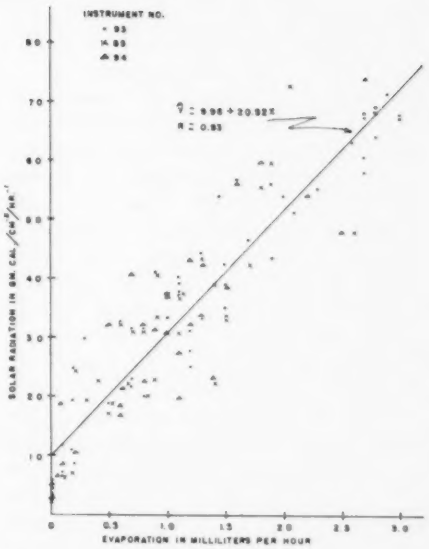


FIGURE 2. *Comparison of evaporation from Gunn-Bellani integrator and solar radiation.*

high correlation indicates a very close relationship between the solar radiation measured by the Eppley pyrheliometer and the amount of evaporation from the radiation integrator. If these instruments had been side by side it would be expected that the relationship would be better. The relationship data for daily periods would be expected to be less scattered. When means of hourly readings were computed for each day the measured radiation was within 4 gm cal/cm²/hr of the estimated radiation.

The maximum evaporation obtained per hour was 3.3 ml, which was equivalent to about 76 gm cal/cm²/hr. Since this reading was made in July it does not represent the peak of solar radiation which would be about 4 ml/hr. During the experiment the maximum daily evaporation was 20 ml. On that day the total solar radiation was 507 gm cal/cm². Total daily solar radiation should rarely exceed 800 gm cal/day in any locality (Smithsonian Institution, 1951). This would be equal to about 32 ml of evaporation. The 40 ml burette

allows for daily observations in any region.

The transmission characteristics of the glass jacket of the radiation integrator are not known. If the total short wave radiation which falls on a body is the desired measurement the correlation found shows this instrument is satisfactory. Pereira (1957) has shown the radiation integrator readings to be closely related to evaporation from an open pan. If only certain wave lengths are of interest, such as the part of the spectrum used in photosynthesis, then the spectral distribution of the light must be considered. Kimball (1924) has pointed out that the radiation intensity measurements for clear sky conditions, expressed in gm cal/min/cm$^2$, can be multiplied by 6700 to give the illumination intensity in foot candles with an error of $\pm$ 5 percent. For a cloudy sky the conversion factor is near 7000. Since the visible wave lengths are a relatively constant part of the total solar spectrum, averaging slightly over 40 percent, the Gunn-Bellani instrument could be useful in measuring light under natural conditions, except at very low intensity. However, when the spectral distribution might be changed considerably, such as under a plant canopy (Geiger, 1950), the relationship could be different than that presented. Before the instrument is used under these conditions, this problem should be investigated further.

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# *Comprehensive and Economical Designs for Studies of Spacing and Thinning*

BY
J. HARRY G. SMITH

STUDIES OF SPACING are concerned with trees grown at relatively constant intervals until harvest. In spacing studies the trees grow without competition until the roots and crowns of adjacent trees meet, then competition among the trees increases until harvest. Thinning studies, on the other hand, assess the results obtained from various degrees of cutting in immature stands, and hence, various spacings. In thinning studies the degree of competition depends upon the initial spacing and upon the kind, frequency, and intensity of thinning. By combining studies of spacing and thinning in comprehensive and well designed experiments, it is possible to derive fundamental and useful silvical data at moderate cost.

Results of many experiments have been published, but there are few conclusive recommendations as to optimal initial spacings and schedules of thinning. Satisfactorily complete studies have seldom been undertaken because of the large forest areas and quantity of work considered necessary to their establishment. Data on the full range of possible treatments are urgently needed to point the way toward the most desirable schedule from silvical and economic viewpoints. In current studies of spacing and thinning in both plantations and natural stands, attention should be paid to the possibilities of broadening the scope of investigations, reducing their cost, and making them more effective by full use of regression and other statistical techniques.

This report outlines the information required from studies of spacing and thinning, reviews available experimental designs, and states some advantages of using a fixed number of trees, individually described trees, and a moderate size of isolation area or "surround." An experimental design that has been employed in several projects is described to illustrate an inexpensive and effective approach to establishment of studies of spacing and thinning. Analyses of data from other studies suggests that these designs will prove to be adequate but not elaborate.

## *Silvical Objectives*

Silvical studies of spacing and thinning should be concerned primarily with the determination of the chances of survival until harvest and the growth in d.b.h. and height for trees by current d.b.h. and crown class. For each species, the age at which competition begins at various spacings over the range of site involved, as well as the effect of varying degrees of competition on the ability of individual trees to respond to release, should be determined.

Because naturally established stands vary

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so much in number, kind, and distribution of trees per acre, information of the greatest and most lasting value will likely come from observation of the growth of trees in plantations, or in natural stands in which spacing has been brought under control at an early age. Data secured on trees grown at regulated spacing distances are based on full use of the site. They may be related to the more irregular natural stands by conversion factors such as summarized by Davis (1954). It is likely that fundamental relationships derived from study of trees grown at carefully controlled spacings will be generally applicable in the management of natural stands.

### Economic Objectives

The way in which a stand actually is grown will depend upon its intended use and its ownership. Quality considerations may impose a moderate restriction on the number of rings per inch. The land owner may choose among maximum volume, maximum value, or maximum return on his invested capital, or may simply take what comes.

Since the decision as to kind, intensity, and frequency of thinning is largely economic, it should be possible to prescribe, theoretically, schedules that will be well suited to most situations. In order to work most effectively, however, the forest manager must have good silvical and economic data. He must know silvical factors related to survival and growth and, in addition, the costs of logging trees of various sizes, the increase in value associated with increase in size, the number and distribution of trees per acre, and the required rate of interest. Operational data should be collected separately from silvical data in most cases, and, preferably, from actual thinning operations.

### Data Required

Studies of spacing and thinning are most concerned with the measurement of current quantities and estimation of trends in variables such as volume, basal area, and numbers of trees per unit-area. Additional variables of interest describe the average trees in terms of volume, height, d.b.h., rings per inch, form, length of live crown, bark thickness, and branch size. The frequency distribution of tree variables is of special importance in relation to the size at which trees become merchantable. Attributes such as resistance to hazards, habit of growth, and similar factors may be expressed as proportions of numbers of trees within a stand.

Because it is conventional to report volume, basal area, and number of trees per unit-area, the practice of using plots of a fixed size for comparisons of various spacings and schedules of thinning has evolved. With area fixed, the number of trees usually is allowed to vary. It will be shown that considerable savings can result from the use of a fixed number of trees rather than a fixed area.

### Usual Experimental Designs

Conventionally, experimenters have demanded large plots and the associated large surround for studies of spacing and thinning. They have found the establishment and analysis of the desired number of plots expensive, and the attainment of sufficiently large and uniform areas difficult.

Very few of the approximately 120 tests of spacing and the numerous trials of thinnings listed to date in *Forestry Abstracts* have used optimum statistical designs. Cromer and Pawsey (1957) suggested that only two of the spacing experiments reported to date had been of adequately replicated randomized-block design. Much improvement could result from making full use of regression techniques, from intensive study of individual trees, and from use of a fixed number of trees rather than fixed areas.

Joergensen (1957) presented a thorough assessment of thinning techniques and underlying principles. He included, however, a conservative appraisal of the potential uses of regression and suggested that, for complete experiments, 20 plots in ran-

domized blocks would be required since not less than 11 degrees of freedom should be provided for the estimate of the error. Quenouille (1953) pointed out, however, that differing experimental conditions can easily make 5 degrees of freedom adequate or more than 10 inadequate.

It is necessary, moreover, to distinguish between replications used to assess *differences in kind* from those used to assess *differences in degree* (Wicht, 1948). Since in evaluating influences of spacing and thinning we are primarily concerned with differences in degree we can, and should, make full use of regression techniques to assess the significance of rates of change in the variables of interest. If the range of treatments is large, or the rate of change is rapid, or the variation about the regression line is small, few replicates are needed. By choosing a wide range of treatments we can develop adequate regressions quite economically and can use them confidently.

Regression techniques are widely used in development of standardized test procedures for bio-assay (Bliss and Calhoun, 1954). Snedecor (1956) discussed regression in single-factor experiments in his chapter on factorial arrangement of treatments. Chapter 8A was added in the second edition of Cochran and Cox (1957) to deal with recent developments in factorial experiments including new designs for quantitative variables measured on a continuous scale. Several aspects of these are directly applicable in studies of spacing and thinning.

### Applications of Regression Analysis

Some advantages of regression techniques are shown clearly in analyses presented by Cromer and Pawsey (1947) for radiata pine. All of their regressions on 6 spacing distances (6 ft. to 11 ft.) were significant when compared with the error term from randomized blocks and also were significant when compared with only the three degrees of freedom residual about each regression line. Only one of their deviations from regression, or "residue", was significantly larger than the mean square for error. In all but one case the precision of these comparisons would have been increased substantially by eliminating the test of a quadratic relationship or by combining that with the residue after testing.

Similarly, with data from Eversole (1955) it can be shown that, for trees 6.6 inches and larger, average d.b.h., average height of dominant and codominant trees, and basal area, cubic-foot, and board-foot volumes per acre all increase significantly with the square of the spacing distance which ranged from 4 to 12 feet. The respective "F" values—250, 40, 67, 54, and 10—for the 1 degree of freedom of the regression line in comparison with the residues from regression having 4 degrees of freedom, all exceed the F of 7.71 for a $p$ of 0.05.

These results are clear but further investigation would be required to establish precise regressions for several sites and stands of various ages. In addition, there is a need to provide an estimate of experimental error for more complete definition of regression lines. Cochran and Cox (1957) suggested that this may be obtained by replication of all levels, by replication of the mid-level, or by use of an estimate for experimental error obtained from previous experimentation.

In a personal communication dated January 15, 1958, D. A. N. Cromer made a good case for replication in blocks by stating that it is necessary under heterogeneous conditions and when the number of treatments is small.

Undoubtedly, replication by blocks should be used where possible. But plots replicated only in degree may provide results of considerable value if they are randomly established and the data carefully analyzed. When block replication is possible, we can often let blocks represent site or similar variables of interest provided that we take care in interpretation (Cochran and Cox, 1957). In long-established trials of

spacing and thinning, where there is doubt as to the adequacy of replication and when site and treatment are confounded, covariance techniques could be used to adjust results to a common basis, thereby permitting salvage of some useful information.

### Correlated Curve-trend Designs

An early approach to extraction of a maximum amount of information from a trial of spacing and thinning by the use of many coordinated replications in degree was initiated in South Africa by O'Connor (1935). Improvements were suggested by Craib (1939, 1947). Marsh (1957) reported that 26 correlated curve-trend experiments have been established in South Africa. He gave important conclusions on yield of pines and outlined a very useful method for the analysis of such experiments.

O'Connor's method assessed yields from stands representing 8 densities maintained throughout their rotation. Numbers of trees used were 1,200, 600, 400, 300, 200, 150, 100, and 50 per acre. Other plots were allowed to become suppressed to varying extents for assessment of response to subsequent thinnings. All stands were established at 6 ft. x 6 ft. spacings initially and were thinned to develop the wider spacings just before mean diameter growth was reduced through competition. The practice of thinning from 6 ft. x 6 ft. was adopted because of weed competition.

By following this method involving eight 1-acre plots on each of good, medium, and poor sites, yield tables can be developed to represent all ordinary combinations of site, initial spacing, and thinning regimes. Wicht (1952) objected to the use of single non-replicated sets of plots; however, block replication within site, although preferable, is not essential.

A modification of O'Connor's correlated curve-trend approach using smaller plots has been applied to a stand of 16-year-old Douglas-fir at the Cowichan Lake Forest Experiment Station of the British Columbia Forest Service on Vancouver Island (Joergensen, 1957).

### Revision of O'Connor's Design

The correlated curve-trend design can provide much information but it requires relatively large areas of fairly uniform land and involves a great many trees initially. If we accept conclusions based on 50 trees at the widest spacing, why not use the same number of trees throughout all spacings?

There is a good precedent for using a small, fixed, and carefully measured group of trees: when assessing plots, most foresters actually use a sub-sampling procedure involving intensive measurements of relatively few trees. Bickford (1954) showed that the use of individual-tree data effected a significant reduction in residual variation.

The advantages of using a constant number of trees have already been recognized in genetic studies (Wiesehuegel, 1952; Edwards, 1956). A number frequently suggested is 121, inclusive of 2 rows of surround, to give 7 x 7 or 49 as the number of trees actually used. Joergensen (1957) reported general agreement that there should be no fewer than 50 trees per plot available for analysis at the end of the experiment.

At Haney, B. C., five spacing distances are being tested on 0.47 acre rather than the 5 acres that would be required in O'Connor's approach. The savings in area reduce variation and facilitate true replication.

### A Trial with Number of Trees Fixed

To test the use of a fixed number of trees rather than fixed area, Cromer, of the Forestry and Timber Bureau of the Commonwealth of Australia, took two samples of 25 radiata pines (1 and 2) from each of the plots reported by himself and Pawsey (1957). Each group of 25 trees was surrounded by several comparable rows. The results are presented in Table 1 by mean d.b.h., weighted by basal area, and by basal area per acre. The fitted values for the two samples representing their three blocks and six spacing distances are nearly identical and agree closely with the values derived

from 1/5-acre plots.

In his letter of March 19, 1958, Cromer concluded "There is no doubt that these figures support your contention, especially as the smaller area would enable a more uniform site to be selected. The reduction in labour, both of establishment and measurement, is enormous."

Further analysis of the data supplied by Cromer shows that the average standard deviation of d.b.h. in the 18 groups of 25 trees used in sample 1 to represent 6 spacings on each of three blocks amounts to ± 1.61 inches. The standard deviation increases moderately with spacing and with d.b.h. This effect could be minimized statistically by appropriate scaling or transformation of the data prior to analysis. A coefficient of variation of 24 per cent describes variations in d.b.h. quite well for most groups of 25 trees. The average standard deviation among all groups of 25 trees is ± 1.37 inches before the regression on spacing is removed and ± 0.32 inches afterwards.

For these data only 22 trees need be measured from each block and spacing plot to determine its mean d.b.h. within 10 percent of the true value 19 times out of 20. Measurement of 22 trees in comparison with those actually measured, 72 at 11 x 11 ft. and 242 at 6 x 6 ft. spacings, would indeed have reduced cost greatly with no apparent reduction in accuracy. Further savings could have resulted from the use of fewer trees from each plot to define the regressions of the several variables of interest in relation to spacing distance. For example, in these remarkable data the regression of d.b.h. on spacing is so strong that it can be defined with only 1 tree chosen randomly from each of the 18 groups of 25 trees designated as sample 1. In a set of 7 trials of regressions based on one tree chosen randomly from each of 18 plots none differed significantly from that based upon 25 trees from each of 18 plots. The largest of the seven "F" values for the difference between regressions was only 2.46 which will occur commonly with 1 and 32 degrees of freedom.

In general, if individual trees rather than averages are used, from 16 to 25 trees should be adequate for the types of analyses usually undertaken.

### Study of Individual Trees

We would do well to concern ourselves with individual trees and their averaged characteristics in studies of spacing and thinning. Study of variations in individual trees would permit assessment of sampling error within each treatment. This has seldom been done and as a result a great deal of information has been lost that would be invaluable in assessing current projects and planning new ones. We could also use equal numbers of trees by crown

*TABLE 1. Mean d.b.h. and basal area per acre by spacing distances.*

| Sample | Spacing distance in feet | | | | | |
|---|---|---|---|---|---|---|
| | 6x6 | 7x7 | 8x8 | 9x9 | 10x10 | 11x11 |
| | *Mean d.b.h. in inches* | | | | | |
| No. 1 | 5.30 | 5.87 | 6.44 | 7.02 | 7.59 | 8.16 |
| No. 2 | 5.31 | 5.88 | 6.45 | 7.01 | 7.58 | 8.15 |
| 1/5 acre | 5.25 | 5.85 | 6.45 | 7.04 | 7.64 | 8.16 |
| | *Basal area per acre in sq. ft.* | | | | | |
| No. 1 | 177.6 | 167.7 | 157.7 | 147.7 | 137.7 | 127.8 |
| No. 2 | 179.6 | 168.9 | 158.2 | 147.4 | 136.7 | 126.0 |
| 1/5 acre | 177.7 | 168.9 | 160.1 | 151.3 | 142.5 | 133.8 |

class, diameter class, race, or seed lot, with either the tree or the class as the basic unit to which degrees of freedom are assigned. Knowing average size per tree and average distance between trees, volume per acre and other unit-area variables can be calculated directly. Analyses of variations in average tree volume and in spacing distance within a given level of spacing or thinning can be of considerable interest in themselves and would be more valid than the usual assumption that estimates of volume per acre are without error. The increased time spent in calculation would be a minor disadvantage associated with the use of individual trees.

In a personal communication dated January 14, 1958, F. C. Hummel, Mensuration Officer of the British Forestry Commission, reported promising results from his small-scale trials involving the use of individual trees in thinning experiments. Staebler (1956) provided a good example of what can be accomplished through treatment of individual trees as the basic unit. Staebler's (1957) design for a test of commercial thinning is complicated by the need to estimate initial differences in stand volume. It might have been simplified considerably could sampling have been based on individual trees and on extremes rather than on averages of volume.

### *Use of Surround*

In experiments concerned with degree of thinning or with spacing, large surrounds are unnecessary. Unlike provenance trials, a thinning or spacing plot will seldom be a total or even a substantial failure. Therefore it is unnecessary to design a strip to provide isolation from large differences in stand height. Initial use of two rows of trees should be adequate and, even within these, we have some opportunity to use regression techniques to assess the influence of spacings within and between adjacent plots. It would be far cheaper and much more instructive to assess trends across plots than to create large surrounds.

### *An Application of Improvements in Design*

A study of spacing and thinning that was initiated on the University of British Columbia Research Forest at Haney in the fall of 1957 illustrates most of the desirable features just discussed. It involves fixed numbers of trees for study of spacing, fixed areas for studies of kind of thinning, and limited yet adequate surround, and it is likely to prove both comprehensive and economical. Analyses will involve individual trees, and regression techniques will be used throughout for the study of the three species, viz., Douglas-fir, western redcedar, and western hemlock.

The five spacings comprise 3 ft. x 3 ft., 6 ft. x 6 ft., 9 ft. x 9 ft., 12 ft. x 12 ft., and 15 ft. x 15 ft. Three blocks have been established for Douglas-fir. Block 1 contains a one-half-acre plot for each of the 5 spacings. Blocks 2 and 3 each contain 5 plots with 7 x 7 or 49 trees at each of the five spacings.

Each of the plots containing 49 trees in blocks 2 and 3 can be arranged in any convenient fashion providing that there is no bias in the allocation of planting stock or of designation of plot location in the field. Because of the unequal area of their plots, blocks 2 and 3 are roughly triangular in shape. These blocks can be fitted together to form a rectangle with the dimensions 294 feet by 168 feet or other shapes that are convenient. Plot size ranges from ¼-acre for 15 ft. x 15 ft. to 1/100-acre for 3 ft. x 3 ft. spacing. Each block totals about 0.57 acre. In comparison with many spacing studies, this represents an immense saving in area, a resultant increase in uniformity of site quality, and, if replicated as with blocks 2 and 3, an improved design in comparison with O'Connor's.

All failures will be replaced up to a tree age of three years and all natural seedlings will be weeded out as required. In blocks 2 and 3, isolation strips are internal and it is planned that the basic units analysed will be each of the 16 or 25 trees closest

to the center of each spacing plot. No thinning will be done in spacing blocks 2 and 3. Average spacing of the representative trees will be determined at each measurement. All estimates required on a per-acre basis will be related to area through numbers of trees and average spacing per tree. These blocks are designed to provide information about the influence of an initial spacing maintained without thinning.

All of the half-acre plots in block 1 will provide much-needed information about the effects of differential initial spacings combined with thinnings. One-half of each of the plots established at the five spacings probably will be thinned mechanically by removal of alternate rows as soon as average growth in diameter becomes less than that of free-growing trees. The other one-half of each plot probably will be thinned numerically by "free thinning" to leave the 49 best trees on the one-quarter acre, with less regard for spacing. This procedure will permit comparisons of stands thinned without restriction of growth to arrive at 15-ft. x 15-ft. spacing with stands planted at initial spacings of 15 ft. by 15 ft. It will also permit a split-plot comparison of mechanical and numerical methods of thinning.

Pruning will be applied to the 49 crop trees in each sub-plot of block 1 as soon as these can be identified. No pruning will be done on block 2 since the influence of a dense canopy on formation of the humus layer is of interest. All trees in block 3 will be pruned as required to maximize the production of clear wood.

### Further Modifications

Practical application of the data on spacing and thinning in regions where there is little market for small trees might have been furthered by use of five spacings ranging from 4 ft. x 4 ft. to 20 ft. by 20 ft. or by inclusion of a sixth spacing 18 ft. x 18 ft. in the original experiment.

From a mensurational point of view, there may be little value in testing the thinnings just described since these involve variations in kind that can be appraised by alternative methods. If thinning is applied just after competition is indicated by a reduction in d.b.h. growth in the next most dense class, the *increased* volume to be gained from thinning can be determined easily from a tally of trees that become surplus as competition begins at each spacing distance. All that is required is a regression of age of suppression over number of trees per acre or some more sophisticated index of spacing such as the ratio of mean height to mean d.b.h. as used by Marsh (1957). Thinnings from plots of equal area then would be useful only in showing the improvement resulting from selection of the 49 best trees from the varying numbers initially available at each spacing. Of course, inferences on this question can also be drawn from assessment of the variations in size or quality of individual trees prior to the onset of competition, for each level of spacing.

For example, assuming inherited superiority of the largest trees, Cromer's data can be used to show that thinning to favor the largest trees for a final spacing of 15 ft. x 15 ft. from an initial spacing of 3 ft. x 3 ft. could eliminate 96 percent of the trees and raise the final average stand diameter by 35 percent. Thinning from 6 ft. x 6 ft. to 15 ft. x 15 ft. could eliminate 84 percent of the trees and raise the average stand diameter by 27 percent. Thinning from 9 ft. x 9 ft. could eliminate 75 percent of the trees and raise the average stand diameter by 24 percent.

The influence of all useful degrees of suppression upon rate of growth can be determined fully from the fixed numbers of trees in the spacing blocks at Haney. Since we can assume that effective competition starts as soon as the average d.b.h. growth in the densest plot drops significantly below that of the next-most-dense plot, and so on, the ages at which competition becomes important for various spacing classes can be determined easily. Once the rates of free growth and of fully suppressed growth have been obtained from the spacing study,

the influences of thinnings ranging in aims from the maintenance of free growth to the development of complete suppression can be interpolated.

When it is considered necessary to confirm the influences of kind of thinning by means of field studies, the number and average spacing of trees required at the *end* of the experiment should be decided. The number to be studied initially then would be the product of the squared ratio of final to initial spacing distances and the final number of trees on each plot as decided. This actually means the fixing of the initial plot area by determining the final number and spacing of trees. All plots in a thinning series of this type will be of the same size unless a smaller final number of trees is planned for plots of initially dense spacing. The final number could be set as low as 16 for initially close spacings, with a maximum of 49. A plot at each spacing smaller than the final one would be required for each of the kinds of thinning under study.

If we must know the exact degree of response to release after various degrees of suppression, a fixed number of trees can be allowed to grow for the desired number of years under competition or until the desired rate of growth develops at each spacing. Blocks identical to "2" or "3" of the Haney study could be developed for each desired degree of suppression.

Spacing studies to evaluate the influence of species mixtures are important and should be initiated as soon as possible. Elements of the Haney design could be applied in such studies.

Provenance and other studies in forest genetics could be improved by planning for replication in the form of plots established to cover a broad range of spacing distances.

## Conclusion

Since data on yield are essential to planning in forestry, simple and comprehensive designs of the type suggested here should be developed locally and applied in plantations or very young stands over a wide range of site quality and for the species important to each forest region. A constant number of trees can be used in all plots established for studies of spacing.

As O'Connor suggested in 1935 and as subsequent South African studies have shown, a series of spacing and thinning experiments can provide the silvical data and much of the economic data required to facilitate choice of the kind, intensity, and frequency of thinning.

Most thinning trials in natural stands could be improved if their objectives were clarified and if planning were based upon fixed numbers of trees over a sufficient range of spacing distances.

In all studies of spacing and thinning, very real advantages can be gained by the use of regression techniques, data for individual trees, and a relatively small final number of trees that is fixed after consideration of the requirements of the study.

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### *Reprints of List of Forestry Theses Compiled by Oregon State College*

Reprints of the list of forestry theses published on pages 293 to 319 of this issue of FOREST SCIENCE are not now available. However, the type has been held by the printer and anyone wishing to order reprints at $1.25 per copy should write the Society of American Foresters, Mills Building, Washington 6, D. C., advising of needs. If the demand is sufficient, reprints will be printed. If not, then those needing copies of the theses list may obtain them by purchasing individual copies of the September issue of FOREST SCIENCE at $2.00 per copy.

# *Hybridization Between Douglas-Fir And Bigcone Douglas-Fir*

BY
KIM K. CHING

AMONG recognized species of the genus *Pseudotsuga* distributed in the temperate zone, two are native to western North America: Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco and bigcone Douglas-fir (*Pseudotsuga macrocarpa* (Vasey) Mayr). Their distribution and growth pattern, however, are dissimilar. As Duffield (1950) pointed out, the Pacific Coast Douglas-fir, as a timber tree, is without a close rival in the genus. This variety, however, is difficult to establish on south slopes or comparatively dry sites in the northwest region, while *P. macrocarpa* grows well on dry and poor sites in areas such as the Angeles National Forest in southern California.

If a hybrid of these two species could be developed, a tree might result with the suitable wood properties and rapid growth of Douglas-fir and the dry-site adaptability of bigcone Douglas-fir. With this possibility as an objective, Jack F. Gartz of The Oregon Forest Lands Research Center initiated an experiment designed to produce a hybrid of the two species.

After initial pollination, the work was taken over by the author. This paper reports background information about parents, method of controlled pollination, results of the cross such as seedling production of the hybrid seeds that resulted from the controlled pollination; also early growth characteristics and morphological features of the hybrid seedlings, and of check progenies from both parent species.

### *The Controlled Pollination*

Four parent trees to be pollinated were selected from a vigorous young stand of Douglas-fir in Oregon State College's McDonald Forest, north of Corvallis, Oregon. The stand was 30 years old, growing on an east-facing slope at an elevation of about 280 meters.

Isolations of ovulate "flowers" were started on April 13, 1956, before the microsporangiate strobili became mature. On each selected tree, a group of female flowers was bagged and subsequently used for controlled pollination. Another group of open-pollinated ovulate flowers on the same tree was used as a check. Self-pollination was avoided by removing all male flowers inside each bag. The sterilized bags were constructed of double layers of canvas with an 8- by 10-cm plastic window.

Branchlets bearing bigcone Douglas-fir male flowers were collected by James Ruppelt, U. S. Forest Service, at the 1,500-meter elevation on Baldy Mountain in Los Angeles County about 15 miles from the city of Glendora, California. The branchlets were shipped by air to Corvallis, Oregon during the early part of March 1956. At that time, the bud scales had burst completely, and the flowers had begun to elongate. The twigs were placed in water in a

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warm room until the pollen was ready to be discharged. Pollen was collected and stored in separate plastic vials at 5°C until used.

The pollination was performed on April 16 and again on April 23 by the standardized method (Duffield 1950, Orr-Ewing 1956).

In the early part of May, after the scales of pollinated cones were closed and the position of cones was no longer upright, the cloth bags were replaced by bags of 20-mesh plastic screen to exclude insects and other intruders. The plastic screen bags also served to prevent loss of seeds if cone collections were delayed or sudden warm weather caused cones to open. The cones were collected September 17, 1956, when they had turned brown. After a storage of four weeks at 26°C, seeds were extracted by hand and stored in sealed bottles at 5°C until used.

Table 1 summarizes the number of cones collected from different trees (both controlled and open pollinated) and seed production per cone. Although there were variations of seed production within types of pollination, the average number of seeds per cone showed no apparent difference.

Since seeds were limited from these test cones, a greenhouse planting was made by sowing all available seed. Viability of each lot was reflected by actual number of seedlings produced. All seed lots were stratified for two weeks at 5°C in moist vermiculite; then on April 16, 1957, they were placed in flats in a greenhouse at 25°C with a relative humidity about 50 percent. Results of germination in the greenhouse are listed in the last column of Table 1.

### Study of Controlled- and Open-Pollinated Progenies

Comparison of progenies from the controlled-pollinated seed with those of open-pollinated ones was necessary so that the hybridization could be verified. All seedlings from hybrid and open-pollinated seeds remained in the greenhouse seedflats for the first growing season. In March 1958, they were transplanted to a 1.2 by 3.3 meter nursery box, filled with sieved and well-mixed fertile forest soil in randomized replicated rows containing 9 seedlings each, with 10 by 15 cm spacing. Some treatments contained incomplete rows due to uneven number of seedlings.

In addition, five bigcone Douglas-fir seedlings obtained from the Industrial Forestry Association Nursery through the courtesy of J. W. Duffield, were used for comparison. The bigcone Douglas-fir seed

*TABLE 1. Comparison of seed production and greenhouse germination between controlled and open pollination.*

| Tree | Type of pollination | Number of cones collected | Average No. of seed per cone | Greenhouse germination (germinated/sowed) |
|---|---|---|---|---|
| DF-1 | controlled | 8 | 36.4 | 18/280 |
| | open | 4 | 17.5 | 53/70 |
| DF-2 | controlled | 7 | 30.4 | 33/210 |
| | open | 11 | 35.6 | 286/390 |
| DF-3 | controlled | 8 | 56.0 | 21/439 |
| | open | 5 | 40.6 | 172/200 |
| DF-4 | controlled | 7 | 49.0 | 15/332 |
| | open | 10 | 51.8 | 305/508 |
| Average controlled pollinated | | 7.5 | 42.9 | 7.85% |
| Average open pollinated | | 7.5 | 38.6 | 73.75% |

was from the 1955 crop, collected on the south side of Mt. Baldy, upper San Antonio Canyon, Los Angeles, California, at an elevation between 1,300 and 2,000 meters. The seed was stratified on March 25, 1957, and was sown on June 6, 1957. These 1-0 seedlings were transplanted during April 1958 into the same nursery box with the controlled-pollinated seedlings.

Several criteria, e.g. seedling height and form, seedling mortality, and needle size and morphology, were the focal points of the study. The methods and results are summarized in the following paragraphs.

#### Height Growth and Tree Form

The total height of all hybrid progenies and about the same number of randomly selected Douglas-fir seedlings resulting from open pollination were measured at the end of the second growing season. In Table 2 are given the values of mean height, the number of seedlings measured, and the average number of branchlets in two-year-old seedlings. Mean height of two-year-old bigcone Douglas-fir seedlings and their average number of branches also were listed for reference.

Height of the two-year-old hybrids varied significantly according to parent trees (Table 3), but that of open-pollinated seedlings was not significantly different among parent trees. The two-year-old hybrid seedlings, as a group, were significantly higher than the Douglas-fir progenies, indicated by the LSD (least significant difference) in Table 2 and illustrated in Figure 1. The number of branches in hybrid progenies was highly variable among parent trees, whereas that of open-pollinated progenies was not significantly different among parent trees although coefficient of variation in the group was large (Table 2).

The hybrid progenies from tree No. 1 showed a distinct pyramidal form and branching habit, both of which are characteristic for bigcone Douglas-fir. The fact that hybrid progenies from the other three

*TABLE 2. Comparison of second-year mean heights, mean number of branchlets, and needle length of bigcone Douglas-fir and controlled and open-pollinated progenies from different maternal trees of Douglas-fir.*

| Tree | Progeny type | Mean height | No. of observations | No. of branchlets | Needle length |
|---|---|---|---|---|---|
| | | *cm* | | | *mm* |
| *Bigcone Douglas-fir* | | 26.74 | 5 | 17.00 | 22.60 |
| *Douglas-fir* | | | | | |
| DF-1 | controlled | 28.63 | 16 | 16.06 | 31.33 |
| | open | 20.44 | 13 | 8.92 | 23.47 |
| DF-2 | controlled | 22.43 | 28 | 6.93 | 28.25 |
| | open | 21.93 | 18 | 6.94 | 29.25 |
| DF-3 | controlled | 24.81 | 18 | 7.22 | 32.75 |
| | open | 21.96 | 14 | 7.64 | 33.50 |
| DF-4 | controlled | 22.75 | 15 | 9.00 | 36.00 |
| | open | 21.73 | 15 | 8.13 | 27.25 |
| *Mean* ±SD | controlled | 24.15±4.78 | | 9.30±4.10 | 31.78±5.16 |
| | open | 21.54±3.46 | | 8.00±3.77 | 23.37±4.88 |
| *LSD* | | | | | |
| .05 | | 1.98 | | 1.91 | 3.97 |
| .01 | | 2.64 | | 2.54 | 5.36 |

trees did not show such trait made this observation inconclusive, and probably it could not be considered as an evidence of hybridization at present. It also was noticed during transplanting that the hybrid lots showed a denser and more fibrous root system. This difference in root pattern may be of great importance to survival as the objective of this study was to produce a hybrid that can be grown successfully in critical droughty sites.

*TABLE 4. Mortality of controlled and open-pollinated seedlings.*

| Tree | Controlled pollination | | Open pollination | |
|---|---|---|---|---|
| | Seedlings | Mortality | Seedlings | Mortality |
| | *Number* | *Percent* | *Number* | *Percent* |
| DF-1 | 17 | 0 | 18 | 27.8 |
| DF-2 | 33 | 9.0 | 27 | 29.6 |
| DF-3 | 20 | 5.0 | 23 | 21.7 |
| DF-4 | 15 | 0 | 18 | 0 |
| | 85 | 4.7 | 86 | 21.0 |

#### Mortality

Counts of survival taken at the end of the second year in the nursery box revealed a difference between the mortality of open-pollinated and hybrid progenies. Table 4 indicates that the ratio of seedlings that failed to survive at the end of the second growing season was a little over 4 to 1 for Douglas-fir progenies. The low mortailty in test progeny may be an indicator of hybrid vigor and could be considered as favorable evidence of hybridization.

#### Needle Characteristics

Morphological and anatomical characteristics of needles have been used by many workers in verifying hybridization (Fowler and Heimburger, 1958; Gathy, 1957; Mergen, 1958; Vidakovic, 1957). An attempt was made to find such evidence. Size of needles, number of stomates, location and size of resin canals, and size of vascular bundles were investigated.

*Needle length, thickness, and width.* Measurements of needles on the leader growth of all test material were made with a binocular microscope (90X) using reflected light for illumination. Width and thickness at mid point of the needles were measured with micrometer to the nearest 1/100 mm,

*TABLE 3. Analysis of variance of second-year height, and number of branches in controlled- and open-pollinated progenies.*

| Observation | Source of variation | D.F. | Mean square | F |
|---|---|---|---|---|
| *Height* | | | | |
| Open-pollinated progenies | Total | 59 | | |
| | Trees | 3 | 6.8038 | .57 |
| | Error | 56 | 11.9645 | |
| Controlled-pollinated progenies | Total | 76 | | |
| | Trees | 3 | 144.6168 | 6.32** |
| | Error | 73 | 22.8746 | |
| *Branches* | | | | |
| Open-pollinated progenies | Total | 59 | | |
| | Trees | 3 | 19.7796 | 1.39 |
| | Error | 56 | 14.1905 | |
| Controlled-pollinated progenies | Total | 76 | | |
| | Trees | 3 | 322.7414 | 19.22** |
| | Error | 73 | 16.7932 | |

**Significantly different at 1 percent level.

and they were not found significantly different. Average needle length for each group is presented in Table 2. The needle size of bigcone Douglas-fir seedlings also is shown in the table for comparison.

Hybrid progenies, *as a whole*, significantly surpassed the open-pollinated progenies in needle length (Fig. 2, Table 2), although variation among trees was obvious. The needles of bigcone Douglas-fir are somewhat wider and fleshier, but are shorter, so the total surface of these leaves is smaller than that of the other two groups. This characteristic of small leaf surface might be of great importance in drought resistance of the plant, as suggested by Runyon (1934).

*Number of stomates.* On the lower surface of the Douglas-fir needle, there is a slightly raised ridge, along each side of which one broad band of stomates is located. Each band is composed of a rather definite number of stomate rows.

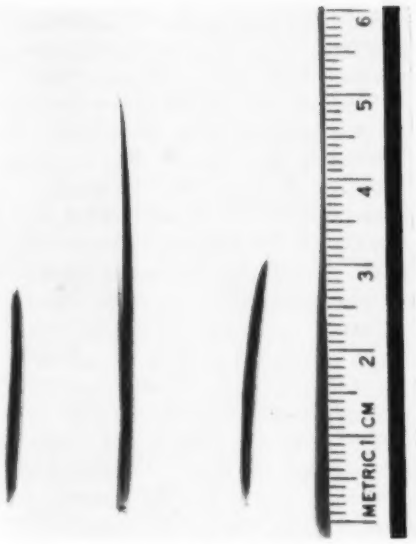


FIGURE 2. *Comparison of needle length of bigcone Douglas-fir (left), hybrid (center), and Douglas-fir (right).*

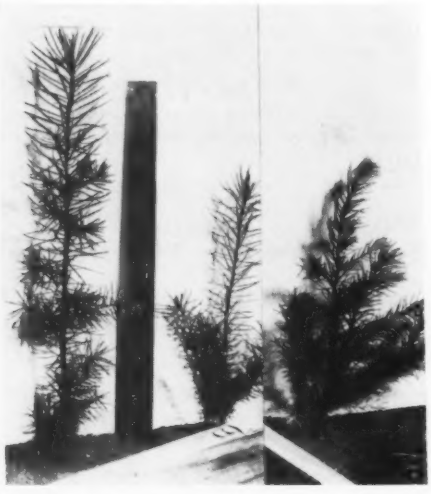

FIGURE 1. *Superior height growth shown by a hybrid seedling (left) when compared with Douglas-fir (center) and bigcone Douglas-fir (right), all of same age (2-0). (The rule is 15 inches long. The superimposed numerals on rule denote centimeters.)*

Fifteen needles each from bigcone Douglas-fir, hybrid and open-pollinated Douglas-fir progenies of tree No. 1, and four needles each from those of the other three maternal trees were examined under a 90X binocular microscope. For the number of rows of stomates per band, a total of 27 observations were made on each kind of progeny, and 200 observations were counted for the number of stomates per unit length of the rows in each of the progenies. It was found that bigcone Douglas-fir, hybrid, and open-pollinated progenies contained $6.9 \pm 0.97$, $8.48 \pm 0.94$, and $7.73 \pm 0.96$ rows of stomates per band, respectiveiy. The hybrid progenies possessed a significantly higher number of rows of stomates per band, as evidenced by a t-value of 2.09, which is significant at the 5 percent level.

The number and standard error of stomates per unit length of row in bigcone Douglas-fir, hybrid, and open-pollinated progenies were $12.62 \pm 0.15$, $11.88 \pm 0.14$,

and 11.03±0.14, respectively. The test progeny was verified by the t-test as significantly different from either parent in this respect. This difference and the intermediacy of the hybrid progeny can be more clearly demonstrated by their frequency distribution in Figure 3.

*Location and size of resin ducts.* Slides of cross sections of needles from the three groups were prepared. Nine needles of open-pollinated Douglas-fir, 6 of controlled-pollinated, and 8 of bigcone Douglas-fir were examined under a compound microscope. All had two resin ducts close to the edge of the needle, and there was no variation in number of resin ducts as would be found in some species of *Pinus* (Vidakovic, 1958). One duct was located closer to the epidermis (peripheral) than was the other (proximate). The mean and standard error of the location of resin ducts as a percentage of half-needle width

$$\left(\frac{A}{B} \times 100\right)$$, where A = distance between the edge of needle to cavity of resin duct, and B = distance between the edge of needle to the central vascular bundle)

and of the diameter of resin ducts are summarized in Tables 5 and 6.

Data in Tables 5 and 6 clearly indicate that resin ducts in the hybrid progeny were the closest to the edge of the needles, while the diameter of resin ducts in the hybrid progeny showed intermediacy between the parents (Fig. 4).

An interesting feature noted in the needle of bigcone Douglas-fir was that there was one incomplete layer of hypodermis bordering the resin ducts, but in other types

*TABLE 5. The mean and standard error of the resin-duct location and the diameter of resin ducts in needles of various progenies.*

| Progeny | Location in percent[1] | Diameter in microns |
|---|---|---|
| *Bigcone Douglas-fir* | | |
| Peripheral | 13.1±1.3 | 47.8±3.2 |
| Proximate | 17.8±1.1 | 52.5±3.9 |
| *Controlled-pollinated Douglas-fir* | | |
| Peripheral | 5.8± .7 | 40.4±2.5 |
| Proximate | 10.8±1.4 | 40.4±2.8 |
| *Open-pollinated Douglas-fir* | | |
| Peripheral | 8.8± .8 | 32.2±2.7 |
| Proximate | 13.5±1.5 | 30.6±2.8 |

[1]Based on half-width of needle.

*TABLE 6. Diameter of vascular bundles in needles of various progenies.*

| Progeny | Thickness | Width |
|---|---|---|
| | ---- *Microns* ---- | |
| Bigcone Douglas-fir | 256.9±12.7 | 312.5±12.6 |
| Douglas-fir | | |
| Controlled-pollinated | 185.0± 4.3 | 221.7± 9.1 |
| Open-pollinated | 160.0± 5.7 | 210.0± 8.3 |

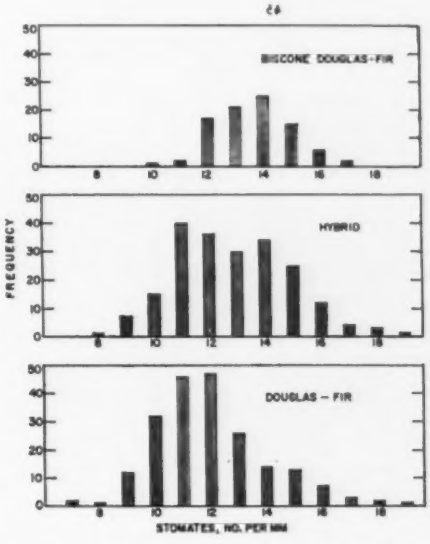


FIGURE 3. *Frequency distribution of stomates.*

of needles only epidermis could be found (Fig. 5).

*Size of vascular bundle.* Bigcone Douglas-fir had the largest vascular bundle, with diameters of 256.9$\mu$ in thickness (dorsal-ventral diameter) and of 312.5$\mu$ in width (bilateral diameter); hybrid progeny, 185$\mu$ and 221.7$\mu$; and open-pollinated Douglas-fir 160$\mu$ and 210$\mu$, respectively (Fig. 4, Table 6). The hybrid progeny was intermediate in this morphological characteristic.

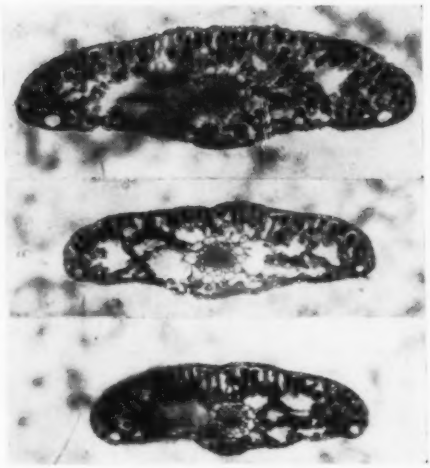

FIGURE 4. *Cross sections of needles showing relative size and positions of resin ducts, and size of vascular bundles: bigcone Douglas-fir (top) hybrid (middle) and Douglas-fir (bottom).*

FIGURE 5. *Enlarged portions of cross-section of needles; bigcone Douglas-fir (top), hybrid (middle) and Douglas-fir (bottom). Note the incomplete layer of hypodermis in bigcone Douglas-fir needle.*

## Discussion

Seed produced from parthenocarpic cones has been reported by Allen (1942) and Orr-Ewing (1957) in Douglas-fir, although the possibility of apomictic formation is very rare. Hybrids produced by controlled pollination nevertheless must be tested to verify hybridization. Results for the criteria studied in testing or verifying the hybridization are listed in Table 7, from which one could conclude that progenies from the controlled pollination probably are true hybrids between Douglas-fir and bigcone Douglas-fir.

As biological individuals, their $F_1$ progenies vary considerably in growth pattern

*TABLE 7. Comparison of criteria used for studying progenies of bigcone Douglas-fir, hybrid, and Douglas-fir.*

| Characteristics | Bigcone Douglas-fir | Hybrid | Douglas-fir |
|---|---|---|---|
| One-year height | ------ | No apparent differences | |
| Two-year height | tall | significantly taller than Douglas-fir | shorter |
| Mortality | ------ | low | high |
| Needle length | shortest | largest | intermediate |
| No. of stomata/mm | largest | intermediate | smallest |
| No. of rows of stomata/band | lowest | highest | intermediate |
| Size of resin ducts | largest | intermediate | smallest |
| Size of vascular bundle | largest | intermediate | smallest |

and morphological characteristics, as shown by the quantitative data. Heterotic and dwarf seedlings both were found in the $F_1$ progenies, even from one maternal tree. Heterosis, of course, is not necessarily the inevitable result of interspecific crossing, nor will it be manifested equally in all crosses between two given species. Hybrid vigor, however, as evidenced by mean seedling height and mean needle length, was observed in progenies from the controlled pollination. Root development, although no support of quantitative data at present, also showed greater vigor in the hybrid seedlings.

An interesting aspect of the experiment, as shown by the data from Table 1, is that the number of seeds per cone appears to bear no direct relationship to the pollen source, and ovules seemed able to develop into seeds upon stimulation by pollen regardless of the occurrence of fertilization or embryo development. The number of fully developed seed, however, was rather low in most controlled-pollinated lots as shown by greenhouse germination results. This may be attributed to low crossability between the species, or, as Allen (1942) pointed out, that empty seeds may be produced as a result of nonfertilization. Low fertility due to nonviable pollen, however, was ruled out by the fact that 30 percent germination was obtained from the same lot of pollen after one year's storage.

It is hoped that the cross between Douglas-fir of Oregon and bigcone Douglas-fir of southern California may produce a type of variety that will have a root system suitable for dry sites, or a synthetic germ plasm containing drought-resistant genes and other desirable characteristics of its parents. There is no indication yet whether the hybrid is a desirable strain. At present, plans are contemplated for further studies of these $F_1$ hybrids whenever the population is built up to such an extent that extensive work can be conducted. Their morphology (root development, form, and cone), physiological behavior (growth rate, drought-resistance potential, and resistance to insect and disease attacks), and cytological characteristics (chromosome number, mitosis and meiosis patterns) will be investigated at appropriate stages of development.

## Summary

An experiment was conducted during 1956 in an attempt to produce a hybrid of Douglas-fir and bigcone Douglas-fir. Female parents of the cross were selected from a vigorous 30-year-old stand of Douglas-fir. Pollen of bigcone Douglas-fir was obtained from trees in southern California.

It was found that crossability of these

two species is rather low, although some fertile seeds were procured. Study of eight characteristics concerning growth, morphology, and anatomy of the hybrid and open-pollinated progenies authenticates hybridity of those seedlings resulting from the controlled pollination.

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### Stem Form and Volume of Japanese Larch in the Netherlands

*By Jan Van Soest. De Dorschkamp. Vol. 4, no. 1. 75 uu. Firma Ponsen & Looijen, Wageningen. 1959.*


*Review by Stephen H. Spurr*
*The University of Michigan, Ann Arbor*


Written in English, this doctoral thesis, submitted to the forestry school at Wageningen, deals with the techniques of tree volume estimation. The data used for the tests were derived from measurements of planted Japanese larch in the Netherlands. Through the use of calipers calibrated directly in terms of cross-sectional area rather than diameter, volume calculations were simplified. Fifteen volume estimation techniques were compared. These included 3 stem form equations, 5 regression solutions, and 7 graphical solutions. Schumacher's logarithmic solution and several modifications of Chapman's harmonized curve solutions were tested, but not the regression solutions presented in the book "Forest Inventory" and in other recent mensurational studies. The best results were obtained from the graphical solutions, and the final volume table was obtained from a modification of the harmonized curve technique.

This study belongs in the small but growing group of comparative mensurational studies which are developing from the application of modern statistical techniques to old-line mensurational problems. It will be of interest to all investigators concerned with the statistical problem of tree volume estimation, and the practical problem of volume table construction. Summaries in Dutch and German are appended.

# *Host Bark Characteristics and Infection By* Hypoxylon Pruinatum *(Klot.) Cke.*

BY
D. W. FRENCH
NAGAYOSHI OSHIMA

In a preliminary study of the growth of *Hypoxylon pruinatum* (Klot.) Cke. on various kinds of agar media it was found that if a sufficiently high concentration of the green layer of quaking aspen (*Populus tremuloides* Michx.) bark was added to the agar, the fungus was inhibited. This suggested that at least this portion of the bark might be inhibitory to the fungus and important in the epidemiology of the disease. Two highly fungistatic compounds, extracted from the bark of *Populus candicans* (Ait.) Gray, in a previous study,[1] inhibited the growth of *Botrytis cinerea* Pers. ex. Fr., *Penicillium italicum* Wehmer, *Aspergillus niger* van Tiegh., and *Rhizopus nigricans* Ehrenb., thus further suggesting the importance of a portion of aspen bark as an obstacle to *Hypoxylon pruinatum*. The work reported here was designed to find out more about the role played by bark layers in hypoxylon canker.

### Materials and Methods

Quaking aspen bark was separated into four distinct layers, the phellem, the green layer consisting of cortex and part of the secondary phloem, and two layers of secondary phloem. Each bark layer was ground in a hammer mill to pass a No. 40 mesh screen. Seventy grams of material from each bark layer were then added to a liter of 2 percent agar. Ascospores, collected from perithecia on naturally occurring cankers, were placed in sterile water and pipetted in approximately equal numbers into each plate of bark medium and into agar plates without bark. The plates were incubated in a desiccator in which the relative humidity was maintained at 96-97 percent. Germinated spores were counted after 48 hours on four plates of each bark medium.

Ascospore germination was compared on the phellem and green layers of *P. tremuloides* Michx. as well as *P. grandidentata* Michx., *P. balsamifera* L., and *P. deltoides* Marsh. Ascospores were suspended in three drops of sterile distilled water on cover slips which were placed on van Tieghem cells in Petri dishes with moist filter paper. Small squares (0.5 x 0.5 cm) of each bark layer were submerged in respective spore suspensions, and incubated at 25°C. Spores in sterile distilled water were used as a check. The test was replicated eight times.

The effect that the bark layers of two of these species might have on the germination of ascospores also was tested by incorporating the bark in agar using 35 and 70

[1]Klöpping, H. L., and Van der Kerk, G. J. M. Antifungal agents from the bark of *Populus candicans*. Nature, Lond., 167, 4259, pp. 996-997. 1951.

The authors are Associate Professor and former Research Assistant, respectively, Department of Plant Pathology and Botany, Institute of Agriculture, University of Minnesota, St. Paul.

Paper No. 4062, Scientific Journal Series, Minnesota Agricultural Experiment Station.

grams of a particular bark layer to a liter of medium. Only the phellem and the green layer were used. Both 2 percent water agar and 2 percent malt agar were used as checks and incubation was at 25°C. To maintain a high relative humidity (nearly saturated atmosphere), which apparently is essential for germination, the plates were wrapped in wax paper and aluminum foil. Fifty spores were counted and eight counts were made for each type of bark.

### Results

The germination of ascospores on each type of media containing a separate layer of bark is shown in Table 1. The highest percentage of germination occurred on the phellem or outer layer of bark, averaging 73.0 percent. In comparison it was 6.5 percent on agar without bark, 0.0 percent on the green layer, 0.5 and 6.0 percent on the two secondary phloem layers. Apparently the phellem stimulates germination while the green layer is strongly inhibitory.

Germination of ascospores on the two outer bark layers of the four Populus species is summarized in Table 2. Germination was stimulated by the phellem of *P. tremuloides*. The green layer completely inhibited germination in the first 24 hours and then the inhibitory effect seemed to decrease and some of the spores germinated. Comparing germination on the bark suspensions of all four tree species at the end of 24 hours, germination was 2.0 percent on the phellem layer of *P. tremuloides*, 0.5 percent on *P. deltoides*, and 0.0 percent on the other two species. The germination percentage of the check was 1.0 percent. After 72 hours, the highest average percentage germination occurred on the phellem of *P. grandidentata* (65 percent) which was three times as high as the check. The lowest germination was 2 percent on the green layer of *P. grandidentata*. The phellem layer of all four species stimulated germination, and the green layer of all species except *P. balsamifera* suppressed it.

*TABLE 1. Germination of ascospores on each of the four bark layers of* Populus tremuloides *after 48 hours at 25°C.*

| Bark layer | Avg. germination (percent) |
|---|---|
| Phellem | 73.0 |
| Green layer | 0.0 |
| Secondary phloem (with stone cells) | 0.5 |
| Secondary phloem (without stone cells) | 6.0 |
| No bark (check) | 6.5 |

*TABLE 2. Germination of ascospores on the two outer bark layers of four different species of Populus*[1] *and on distilled water.*

| Medium | Average germination (percent) 24 hours | 72 hours |
|---|---|---|
| *P. tremuloides* | | |
| Phellem | 2.0 | 52.5 |
| Green layer | 0.0 | 12.5 |
| *P. grandidentata* | | |
| Phellem | 0.0 | 65.0 |
| Green layer | 0.0 | 2.0 |
| *P. balsamifera* | | |
| Phellem | 0.0 | 28.0 |
| Green layer | 0.0 | 63.5 |
| *P. deltoides* | | |
| Phellem | 0.5 | 41.0 |
| Green layer | 0.3 | 13.0 |
| Distilled water | 1.0 | 23.5 |

[1] The data are the average of four readings. Each reading was the result of counting 50 spores. The spores were incubated at 25°C.

The data on germination on agar containing bark at two levels of concentration are in Table 3. After 30 hours, the percentage of germination was highest on the phellem layer of *P. deltoides* (93.0 percent with 70 grams of bark per liter) and lowest on the green layer of *P. tremuloides* (0.8 percent at 35 grams of bark per liter).

*TABLE 3. Germination of ascospores on agar media containing the ground bark of* P. tremuloides *and* P. deltoides,[1] *on malt agar, and on water agar.*

| Medium | Concentration of bark | Average germination |
|---|---|---|
| *P. tremuloides* | *Grams/liter* | *Percent* |
| Phellem | 70 | 23.5[2] |
| Phellem | 35 | 61.8 |
| Cortex + secondary phloem[3] | 70 | 2.3 |
| Cortex + secondary phloem | 35 | 0.8 |
| *P. deltoides* | | |
| Phellem | 70 | 93.0 |
| Phellem | 35 | 76.5 |
| Cortex + secondary phloem | 70 | 1.5 |
| Cortex + secondary phloem | 35 | 37.5 |
| 2 percent malt agar | | 49.5 |
| 2 percent water agar | | 35.3 |

[1] The data are the average of 8 readings. Each reading was the result of counting 50 spores after 30 hours at 25°C.

[2] The medium dried out during test period.

[3] This bark layer includes green layer and the two layers of secondary phloem.

The low germination of spores with the phellem layer of *P. tremuloides* was attributed to the drying out of the medium during the test period.

Essentially the same results were obtained in all the germination tests with ascospores. The thin outer layer of bark, the phellem, contains material that stimulates early germination and a high percentage of germination. The second, or green, layer of bark slows spore germination and may completely prevent it.

### Discussion

It is still not known how and in what form *H. pruinatum* enters a host but apparently it is possible that the success or failure of the fungus to invade may be determined by what layers of bark are exposed to it. The type of wound and layer of bark which forms the substrate for spore germination may determine whether or not the spores can germinate and if they do how much of a colony can develop. The fact that the green layer inhibits spore germination indicates that some place on the tree where this layer is absent or covered would be a likely point of entry. On the other hand, the outer bark layer stimulates germination and its presence may be necessary for successful infection. Apparently the ascospores will germinate only in a nearly saturated atmosphere and thus time required for germination may be very important.

There is one possible entry point on an aspen tree where these conditions occur. Immediately above a branch axil where the bark of the branch and main stem converge there is, in many cases, one place where the green bark layer is absent and where the outer layer is often folded over the inner layers. A young canker at a branch axil can at times have its source or initial point of entry traced to the place

FIGURE 1. *Longitudinal section of* Populus tremuloides *showing bark formation at a branch axil and a very young hypoxylon canker. The narrow slit in the bark in the branch axil is where the fungus apparently entered the tree.*

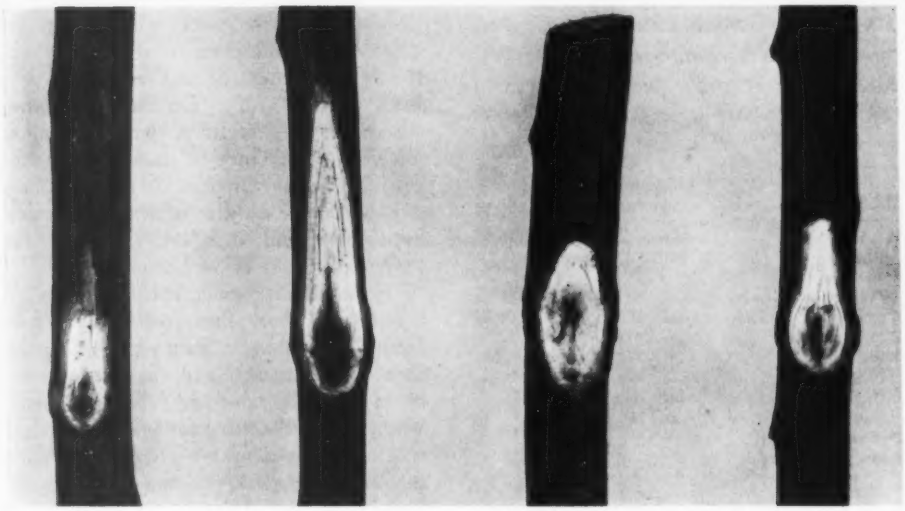

FIGURE 2. *Wounds made by pulling living branches from* Populus tremuloides. *The green layer is absent at the top-center margin of the wounds and fragments of the phellem layer are folded down over the inner layers (for this, note particularly the branch on the left).*

where the branch and main stem bark grow together. In Figure 1 a narrow slit can be seen in the branch axil and in this instance the fungus evidently started here because the deepest penetration has occurred at this point. Figure 2 shows wounds made by pulling branches from the main stem. At the top center of each wound a narrow zone can be seen where the green bark layer is absent, and fragments of the outer bark layer are folded down over the inner bark. There is no direct evidence yet that *H. pruinatum* actually gains entrance to the host through this opening at the branch axil but considering the bark characteristics at this point and the effects that each layer has on the germination of ascospores it seems that this possibility should be explored further.


## Summary

The thin outer layer of bark (phellem) from *Populus tremuloides* increases the percentage germination of ascospores of *Hypoxylon pruinatum*. The green layer (cortex + part of the secondary phloem) immediately beneath the outer layer almost completely inhibits germination. This suggests that spore germination, as a prerequisite to invasion of the host by the pathogen, must occur where the green layer is lacking or possibly where the outer layer covers it. In many branch axils where the bark of branch and main stem converge the green layer is lacking and the phellem is folded over the inner bark layers. It is possible that the fungus is able to enter the host at this point where the conditions are more favorable for the germination of ascospores.

# *Certain Ecological and Phylogenetic Aspects of the Pattern of Water Conduction in Conifers*

BY
J. A. RUDINSKY
J. P. VITÉ

THE DEVELOPMENT of a water-conducting system in plants is one of the elements in evolution that reflects the plant's conquest of a new environment. Naturally, the progress of this development is most pronounced in those plants whose water must ascend a long distance from the roots to the transpiration surface and against the force of gravity, i.e., in trees.

The phenomenon of water transport consists of a static component, the conducting elements, and a dynamic component, the forces effecting the ascent. The water transport in conifers is effected by tracheids, which form the water-conducting elements, or tracheidal conduits or channels. Besides this axial transport of water in the tracheids, some limited radial and tangential translocation also takes place, but it will not be considered here. The present discussion is concerned with the pattern of axial water transport and the arrangement of the conducting elements in the stems of conifers.

A simple method to ascertain the pattern of water transport has been described in detail (Vité, 1959). In brief, acid fuchsin, in a 0.3 to 1 percent aqueous or alcoholic solution, was injected into the trunk through a hole bored into the base of the tree or by means of an injection knife. After a few days, the distribution of the dye within the tree was studied by sectioning the trunk transversely at regular intervals above the point of injection. A clear picture of the existing pattern of water conduction is obtained from the active crown, whereas certain alterations can take place below the active crown that may distort the pattern (Vité and Rudinsky, 1959). Therefore, young trees (10 to 20 years old) as well as middle-aged ones (40 to 80 years) were chosen. In contrast to the methods used and the results obtained by Greenidge (1955 and 1958) in his studies on the water ascent in broadleaf trees, it was found that the dye followed the grain in every instance; the stained pattern obtained was identical to the arrangement of the tracheidal conduits within a stem (Vité 1958 and 1959). Anatomical differences in the xylem structure cause the different patterns of water conduction, although individual specimens within a species may show considerable variation. The study of various conifers led to the detection of five water-conducting systems (Vité and Rudinsky, 1959) which are summarized as follows:

1. *Spiral ascent, turning right:* On the transverse section, the stained pattern forms a spiral band that runs from the outermost growth ring clockwise toward the center of the stem. This type of water

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conduction is present in the investigated species of *Picea*, *Abies*, *Larix*, and Rehder's (Rehder, 1947) Section III (*Taeda*) *of* the genus *Pinus*.

2. *Spiral ascent, turning left:* The spiral band runs counter-clockwise from the periphery toward the center of the crosscut stem. This type is possessed by the white pines of Rehder's Section I (*Cembra*).

3. *Interlocked ascent:* The injected dye forms a zigzag pattern that extends over the transverse section as the distance increases from the injection point. *Sequoia*, *Libocedrus*, and *Juniperus* exhibit the interlocked type of ascent.

4. *Sectorial, winding ascent:* The dye ascends from the point of injection in a sector; however, the stained sector winds around the tree axis as the distance increases from the point of injection. Usually, the dyed sector extends tangentially toward the top of the tree. This type is present in *Tsuga* and *Pseudotsuga*.

5. *Sectorial, straight ascent:* The dyed sector does not wind, as the tracheids run more or less parallel to the stem axis in all layers of the sapwood. The sectorial, straight ascent of water is found in *Thuja* and *Chamaecyparis*.

Further studies provide information on the water-conducting systems of 31 species of conifers belonging to 11 genera and 3 families (Table 1, Fig. 1). They show that closely related species always possess the same pattern of water conduction, as is usually true for related genera. But differences are frequent within the families of conifers. It is very likely that these differences are related to the phylogeny of the species investigated. Before such consideration, however, the possible ecological and physiological advantages for competition and survival should be discussed.

### Ecological Aspects

The continuous change of angle in which the tracheidal conduits are arranged in subsequent growth rings in the *right-turning spiral system*, leads to greater water distribution than in any of the other water-conducting systems. A majority of the branches even in the lower part of the crown are connected with every root (Vité, 1959). Since the connection occurs partly in the outer sapwood and partly in the inner layers through which less water is conducted, the quantitative transport of water is not uniform. But the advantage of the greater distribution of water is obvious: it decreases the danger that loss of individual roots will decrease the water supply of entire tree sectors and thereby render them susceptible to secondary enemies.

From the extensive research already done on the phenomenon of the slope of grain in trees, it is evident that there are considerable individual differences in the arrangement of the tracheids in the xylem of the same tree species (Mayer-Wegelin, 1956; Northcott, 1957). Foremost, therefore, was the question: what causes these individual differences in the structure of a particular water-conducting system? Or from the viewpoint of wood technology: what are the causes of the slope of grain? The following hypothesis suggested itself: the pattern of water transport is influenced by the distribution of water in the crown. From this hypothesis it follows that any changes in the transpiration surface must also cause changes in the arrangement of the tracheidal conduits. Reduction of the transpiration surface (by heavy pruning) not only decreased the diameter growth but also increased the slope of those xylem fibers formed after the pruning (Vité, 1958). Changes in the radial growth are then accompanied by changes in the angle by which the tracheidal conduits deviate from the tree axis (Fig. 2). On the other hand, release of suppressed trees increased the transpiration surface and also decreased the spiral momentum. This was shown by the reversal of later grown tracheids which ran opposite to the fiber of previous years (Fig. 3). Alterations in the directions of tracheids take place at once after pruning, but only some time after releasing.

This phenomenon is important from an

*TABLE 1. Investigated conifers and their water-conducting pattern.*[1]

| Species | Spiral: Right turning | Spiral: Left turning | Sectorial: Winding | Sectorial: Straight | Interlocked |
|---|---|---|---|---|---|
| **PINACEAE** | | | | | |
| *Pinus* spp.[2] | | | | | |
| Section I: | | | | | |
| *Cembra* | | | | | |
| *flexilis* James | | X | | | |
| *lambertiana* Dougl. | | X | | | |
| *monticola* Dougl. | | X | | | |
| Section II: | | | | | |
| *Parrya* | | | | | |
| *monophylla* Torr. & Frem. | ? | | | | |
| *edulis* Engelm. | ? | | | | |
| *aristata* Engelm. | X | | | | |
| Section III: | | | | | |
| *Taeda* | | | | | |
| *attenuata* Lemm. | X | | | | |
| *contorta* Dougl. | X | | | | |
| *jeffreyi* Grev. & Balf. | X | | | | |
| *ponderosa* Laws. | X | | | | |
| *sabineana* Dougl. | X | | | | |
| *Larix* spp. | | | | | |
| *decidua* Mill. | X | | | | |
| *occidentalis* Nutt. | X | | | | |
| *Abies* spp. | | | | | |
| *amabilis* (Dougl.) Forbes | X | | | | |
| *concolor* (Gord. & Glend.) Lindl. | X | | | | |
| *grandis* (Dougl.) Lindl. | X | | | | |
| *lasiocarpa* (Hook) Nutt. | X | | | | |
| *procera* Rehd. | X | | | | |
| *Picea* spp. | | | | | |
| *englemannii* Parry | X | | | | |
| *pungens* Engelm. | X | | | | |
| *sitchensis* (Bong.) Carr. | X | | | | |
| *Tsuga* spp. | | | | | |
| *heterophylla* (Raf.) Sarg. | | | X | | |
| *mertensiana* (Bong.) Carr. | | | X | | |
| *Pseudotsuga* | | | | | |
| *menziesii* (Mirb.) Franco | | | X | | |
| **TAXODIACEAE** | | | | | |
| *Sequoia* spp. | | | | | |
| *gigantea* (Lindl.) Decne. | | | | | X |
| *sempervirens* (D. Don) Endl. | | | | | X |
| **CUPRESSACEAE** | | | | | |
| *Libocedrus* | | | | | |
| *decurrens* Torr. | | | | | X |
| *Juniperus* spp. | | | | | |
| *occidentalis* Hook. | | | | | X |
| *osteosperma* (Torr.) Little | | | | | X |
| *Chamaecyparis* | | | | | |
| *lawsoniana* (A. Murr.) Parl. | | | | X | |
| *Thuja plicata* | | | | | |
| Donn. | | | | X | |

[1] Compare also Figure 1.
[2] According to Rehder, 1947.

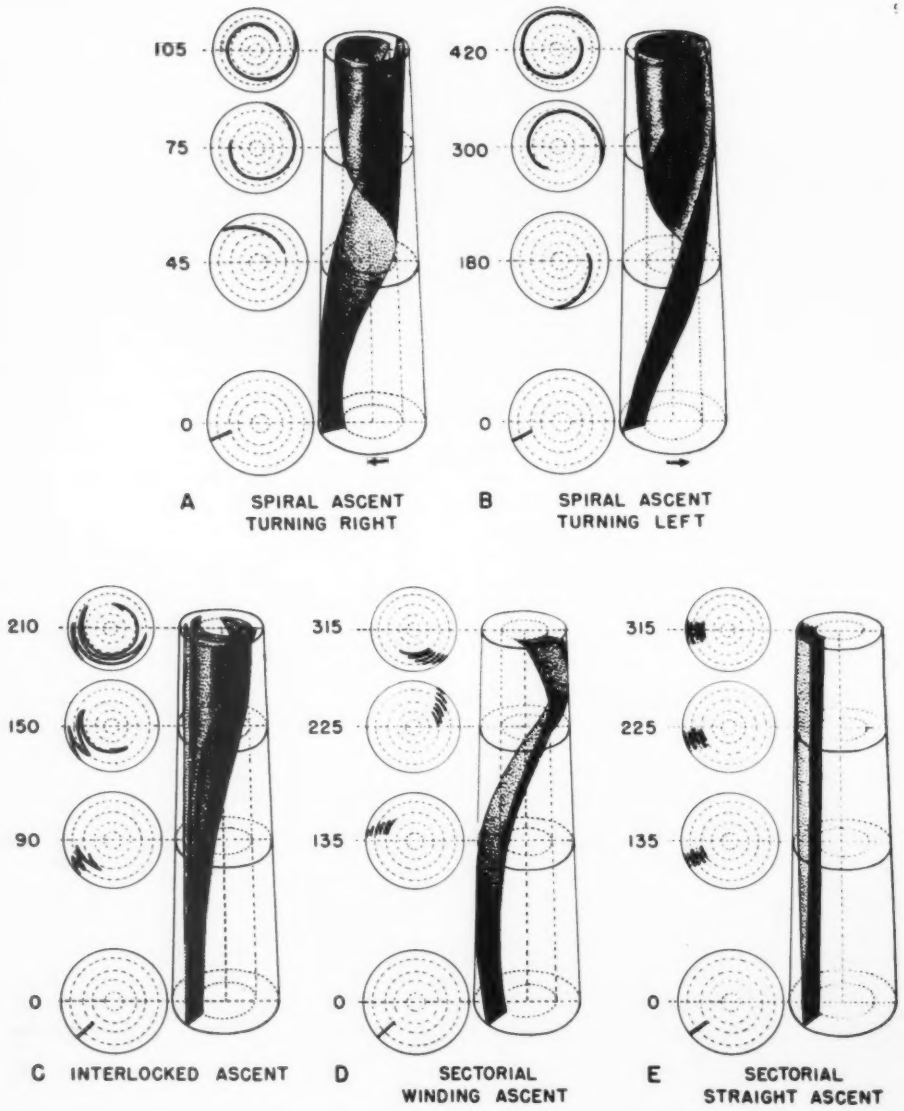


FIGURE 1. *Five types of the water-conducting systems in various conifers as shown by the tracheidal channels that were dyed by trunk injection. The numbers give the height in centimeters of the transverse section above injection. A. Spiral ascent, turning right:* Abies, Picea, Larix, *and* Pinus *(Rehder's Section III:* Taeda*). B. Spiral ascent, turning left:* Pinus *(section I:* Cembra*). C. Interlocked ascent:* Sequoia, Libocedrus, *and* Juniperus. *D. Sectorial, winding ascent:* Tsuga *and* Pseudotsuga. *E. Sectorial, straight ascent:* Thuja *and* Chamaecyparis. *(Courtesy of Boyce Thompson Institute for Plant Research.)*

ecological viewpoint. Trees with the right-turning spiral system may respond quickly to environmental changes and thus may be rendered stronger in competition with other tree species. It should be noted, however, that the same conducting system is present in both extremely tolerant species (*Abies*) and very intolerant ones (*Lariv*).

The *left-turning spiral system* seems to distribute the transpiration water to a smaller degree because of its slower winding momentum, although it is otherwise equal to the right-turning spiral system. All investigated specimens (14 trees of 3 species) showed considerably slower winding momentum. In particular, *Pinus lambertiana*, which was more closely investigated, showed smaller angles of tracheidal deviation, i.e., only three-fifths of the angles exhibited by the hard pines. Differences may exist, however, between species of this group.

The principle of decentralization is also found in the *interlocked system*, although in a quite different form. In this system, the water in the various sapwood layers is transported alternately from one direction to the opposite, so that the injected dye is spread over the transverse section in a zigzag pattern (Fig. 4). In wood technology this arrangement of tracheidal conduits in the xylem is called "interlocked grain." The two-fold ecological advantage of this structure is apparent: first, complete dis-

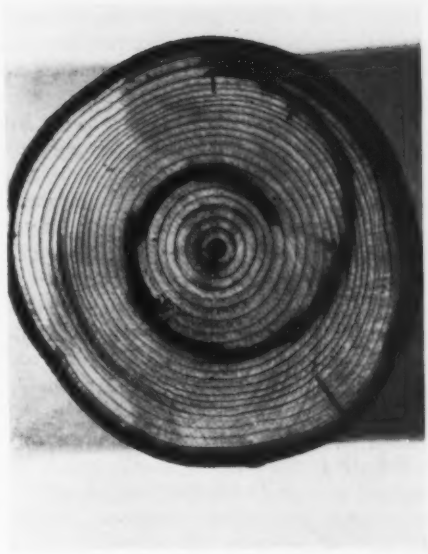

FIGURE 3. *Cross section of white fir* (Abies concolor *(Gord. and Glend.) Lindl., 640 cm above the injection. This fir was released in 1953; by 1955 the tracheidal conduits were reversed. (Dye lightly redrawn.)*

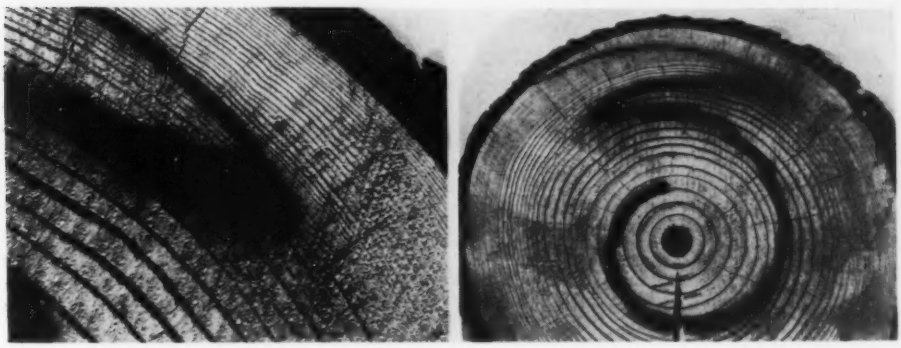

FIGURE 2. *Transverse section of ponderosa pine* (Pinus ponderosa *Laws.) 219 cm above the acid fuchsin injection (left); enlarged detail (right) showing that the change in the orientation of the tracheidal conduits corresponds to the change in radial growth. (Dye lightly redrawn.)*

tribution over the upper crown, to which only the spiral systems are comparable; second, great adaptability in responding to changes in environment—even faster than in the spiral systems, as is shown, for instance, in the fast response of suppressed incense cedar to light by expanding the crown and producing wide growth rings. Therefore, sudden changes, independent of the tracheid direction of the previous growth rings, are typical of this water-conducting system. The same structural pattern allows the eccentric growth of the trunk, with concentration of the sapwood and branches on one side and small or "missing" growth rings on the opposite side of the tree axis. Trees with such a water-conducting system commonly grow in groups, as *Sequoia sempervirens*, *Juniperus* spp., and *Libocedrus decurrens*, rather than as single trees. A one-sided crown can be supplied with water more easily by this system than by the others. Therefore, it may not be accidental that trees with extreme tolerance (*Libocedrus decurrens*), maximal growth (*Sequoia*), and extreme endurance of dry conditions (*Juniperus*) possess this system.

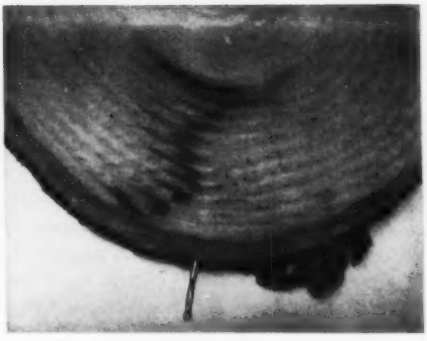

FIGURE 5. *Transverse section of the trunk of a Douglas-fir* (Pseudotsuga menziesii *(Mirb.) Franco) 400 cm above injection. In the early springwood of each growth ring the stained pattern deviates far more to the left than in the late springwood and summerwood.*

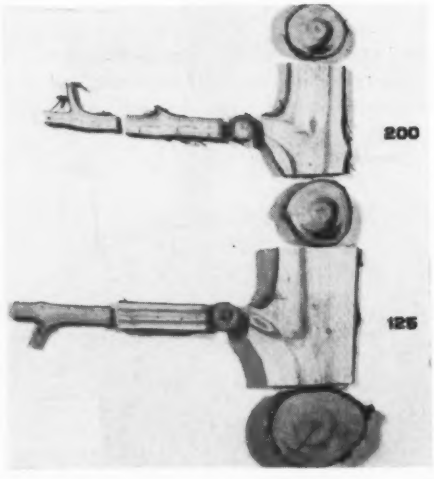


FIGURE 4. *Transverse and radial sections of the trunk and branches of a 37-year-old western juniper* (Juniperus occidentalis *Hook.) after being injected with acid fuchsin. The numbers give the height above the injection in centimeters.*

The *system of sectorial, winding ascent* of water was studied most intensively on Douglas-fir.[1] Although the distribution of the transpiration water seems to be limited by the sectorial ascent, this species possesses other means of extending the area supplied from a single root. The dye injections showed that the early springwood always deviates to the left of the later springwood and the summerwood in each growth ring. The result is that a larger circo-lateral portion of the growth ring is supplied from each root than would occur in a sapwood with parallel run of the tracheidal conduits in all layers of the growth rings (Fig. 5). Therefore, a larger number of branches are directly connected with each root than would be expected from the actual size of

[1]Personal communication from Mr. William H. Hendrickson, Boyce Thompson Institute Forest Research Laboratory, Grass Valley, California.

the root at the base of the stem. In addition, the winding of the tracheidal conduits around the stem axis may provide a certain flexibility in responding to environmental changes.

The tracheidal structure found in *Thuja plicata* and *Chamaecyparis* seems to correspond to the concept of more or less straight ascent hitherto accepted as common for the transpiration stream of conifers. Lacking means of decentralizing the transported water, this system of *sectorial, straight ascent* must appear as the most primitive.

It may be pointed out that the decentralization of tracheidal conduits is much more important in the distribution of water than the actual length of the pathways. Moreover, prolongation of the tracheidal conduits resulting from the spiraling cannot be considered a disadvantage because of its minute change.

### Phylogenetic Aspects

Consideration of the water-conducting systems naturally raises the question of genetic relationship. In most cases, the present taxonomic arrangement of conifers accords with the structure of the water-conducting elements. Nevertheless, in some instances there are surprising discrepancies. These gain prominence particularly in a consideration of the "degree of relationship."

In Pinaceae at least three distinct water-conducting systems are present (Table 1). Although all the investigated species of *Larix, Picea,* and *Abies* show the same type of water conduction, the differences within the genus *Pinus* are especially striking. The right-turning spiral system is present only in the observed hard pines of Rheder's Section III (*Taeda*) and in *P. aristata*, belonging to Section II (*Parrya*). Considering the water conduction, these pines show a closer relationship to each other than to the white pines of Section I (*Cembra*), which possess the reverse, left-turning spiral system. The striking differences in the water-conducting systems of white pines (Section I: *Cembra*) and hard pines (Section III: *Taeda*) substantiate the hypothesis that the two groups split early and underwent parallel development (Mirov, 1958). Moreover, Section II seems also to contain species that possess a quite different water-conducting system, comparable neither to that of the hard pines nor to that of the white pines of Section I. That is, specimens of *P. monophylla* and *P. edulis* did not correspond to any of the water-conducting systems yet described.

*Pseudotsuga menziesii, Tsuga heterophylla,* and *T. mertensiana* show the quite different water-conducting system of sectorial, winding ascent. However, there exist certain similarities to the right-turning spiral system present in the larger number of Pinaceae species. One is the tendency of tracheidal conduits to turn with age from the left to the right side of the tree axis. Another similarity may be seen in older trees, which frequently show right-turning semi-spiral ascent. In contrast to the right-turning spiral system, however, the semi-spiral is confined to only a sector of a transverse cut.

In Cupressaceae, *Libocedrus decurrens* and *Juniperus* spp. appear more closely related to each other than to *Thujo* and *Chamaecyparis*. Among the Taxodiaceae and Cupressaceae, which are considered closely related, it is striking that *Sequoia, Libocedrus,* and *Juniperus* possess the same interlocked system of water conduction, whereas *Thuja* and *Chamaecyparis* show sectorial, straight ascent of water. The especially close relationship indicated among *Sequoia* spp. and *Libocedrus decurrens* is supported also by a number of morphological similarities. Questionable, therefore, is the new systematic arrangement of *Libocedrus decurrens* Torr. 1854 as *Heyderia decurrens* (Torr.) and Koch 1873 (Florin and Boutelje, 1954; Li, 1953) in the subfamily Cupressoideae (tribe Thujopsideae), because the genus *Thuja* possesses a quite different water-conducting system and xylem structure. It is believed that further study of conducting systems can shed light espe-

cially upon the genera of the family Cupressaceae.


### Summary

The ecological and phylogenetic significance of five water-conducting systems is discussed. The criterion used was whether the water ascending through a given sector of the lower tree stem is distributed to a small portion or to a rather large portion of the transpiration surface. Thus, the sectorial, straight ascent and limited distribution of water in certain Cupressaceae is considered to be less effective than the interlocked ascent of water with considerable distribution over a large portion of the transpiration surface, which is present in other genera of the same family. The most complete distribution, however, is exhibited by a system of spiral ascent with great winding momentum, which is common in genera of Pinaceae (spiral, right-turning ascent). In the same family two genera (*Tsuga* and *Pseudotsuga*) show an intermediate structure in their water-conducting system. This system still bears the feature of sectorial ascent, but it provides more extensive water distribution by a semi-spiral arrangement of the tracheidal conduits in adjacent growth layers. Striking differences in the water-conducting systems within the genus *Pinus* confirm the genetic diversity indicated by other workers.


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# *The Effect of Available Soil Moisture On the Mycorrhizal Association Of Virginia Pine*

BY
J. F. WORLEY
EDWARD HACSKAYLO

FOR SOME 70 YEARS investigators have observed and reported the mycorrhizal association between roots of woody plants and certain soil fungi. Often two or more species of fungi are mycorrhizal on a single host plant. One of the fungi more commonly found on the same host with other species is *Cenococcum graniforme* (Sow.) Fred. and Winge, its black mycelium contrasting sharply with the lighter-colored mycelia of other ectotrophic fungi. Usually, in such joint associations, less than 10 percent of the total mycorrhizal roots are invaded by *C. graniforme;* only occasionally is it the sole or predominant organism involved (Hatch 1934, Rayner 1934, 1935, Mikola 1948, Palmer 1954).

Palmer in 1954 reported that *C. graniforme* mycorrhizae were abundant in nature during dry summers but lacked competitive ability in moist humus. Based on this and our own field observations, experiments were initiated to study the effect of controlled soil moisture levels on the percent of *C. graniforme* mycorrhizae on Virginia pine (*Pinus virginiana* Mill.).

Pine seed were germinated in flats containing No. 2 Vermiculite and, after two weeks, the seedlings were transplanted into naturally inoculated soil in 3-inch porous clay pots. This soil was taken from a pine forest near Beltsville, Maryland, where we had frequently observed the mycorrhizae of both black and white fungi. The litter was removed and approximately the first 6 inches of soil was taken. Rocks and other debris were removed by using a ¼-inch wire mesh screen. The seedlings were allowed to grow in the potted soil for 2 weeks prior to treatment.

Four relative soil moisture levels, within limits established by preliminary trials, were maintained by watering at different periods. The highest level appeared to be near optimum for growth of the seedlings; at the lowest level many seedlings died from what we assumed to be an improper moisture relationship.

Twenty-four pots were divided into 4 lots as follows: (1) 6 were watered in excess every day; (2) 6 were watered in excess every second day; (3) 6 were watered in excess every third day; and (4) 6 were watered in excess every fourth day. The seedlings were maintained in the greenhouse under the established moisture conditions for 64 days (May-July 1957) and then harvested, the roots washed free of soil and debris and the whole plant preserved in 10 percent formalin. As con-

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This paper is a portion of a thesis submitted by the senior author to The George Washington University, in partial fulfillment of the requirements for the M.S. degree.

*TABLE 1. Average*[1] *number of black and white mycorrhizae per seedling on* Pinus virginiana *grown under four soil moisture levels.*

| Watering Period | White | Black | Percent Black[2] |
|---|---|---|---|
| A—every day | 72.4 | 10.5 | 11.9 |
| B—every second day | 18.4 | 8.3 | 59.9 |
| C—every third day | 0.08 | 8.6 | 98.6 |
| D—every fourth day | 0 | 2.4 | 100 |

[1] Based on 12 plants per treatment from two separate experiments except treatment D where only 6 plants survived.

[2] Average mean deviation for A through D were respectively ±3.5, ±38.2, ±2.5 and 0.

venient, mycorrhizae counts were made by spreading the roots in water and recording the total number of mycorrhizal roots as seen with the aid of a hand lens. The data from two such experiments are summarized in Table 1.

The results indicate that a white fungus, the predominant mycorrhizae-former on pine seedlings under a relatively high soil moisture level, was completely absent at a lower level; and that a black fungus, associated with only about 10 percent of the mycorrhizae under the higher soil moisture content, was the predominant mycorrhizae-former under the lower moisture content. The percentage of black mycorrhizae increased from about 10 percent to 100 percent as the available soil moisture decreased. This increase of black mycorrhizae was not reflected in the total number of short roots invaded per plant, but the root system was appreciably reduced under conditions of low moisture, with the result that the percentage of short roots invaded by the black fungus was increased. It would therefore appear that the black fungus was more vigorous as a mycorrhizal fungus under a relatively low soil moisture level, whereas the white fungus was less vigorous under these same conditions. Hence, under the conditions of these experiments, we were able to alter greatly the mycorrhizal association of *P. virginiana* by controlling the relative amount of available soil moisture.

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# *Predicting Weevil-Caused Volume Loss In White Pine*

BY
ROBERT J. MARTY

THE WHITE-PINE WEEVIL (*Pissodes strobi* Peck) causes extensive damage to eastern white pine (*Pinus strobus* L.). Along with white pine blister rust, the weevil has been a major factor in discouraging intensive management of white pine throughout the Northeast and the Lake States. Blister rust is under control in many areas, but damage by the white-pine weevil continues unchecked except in those stands where natural control is provided by shading from overstory trees.

White-pine weevil attack brings about two major types of loss. First, destruction of the terminal leader results in forking, crook, and sweep, and causes a *reduction in recoverable volume*. Such volume loss can be severe.

Second, weevil injury causes *lumber degrade in the remaining volume*. Causal defects include cross grain, large knots, loose knots, red rot, and reaction wood. Ostrander and Stoltenberg (1957) report that in a sample of 400 white pine logs taken near Warrensburg, N. Y., lumber degrade due to defects caused directly or indirectly by weevil-like injury resulted in reductions in lumber value ranging from $2 to more than $14 per thousand board-feet, at 1956 wholesale prices.

Progress is being made in the development of new methods for controlling the white-pine weevil. Research in aerial application of insecticides (Connola *et al.*, 1955) should soon provide a practical control method for large areas. And a hand method of control applicable to young stands has already been developed (Crosby, 1954, 1958). The availability of new control methods provides a new opportunity for foresters to increase volume and value growth of white pine.

To evaluate this opportunity, the cost and results of weevil control must be compared. Researchers at the Northeastern Forest Experiment Station are now making an economic analysis of such opportunities. This paper deals with efforts to define the relationship between weevil injury and white pine volume loss—just one part of the information needed to make an economic analysis of protection programs.[1]

## Previous Research

Literature dealing with research on the white-pine weevil is voluminous. Yet only one major study has been reported on the loss in tree volume due to weevil attack. In this study (Waters *et al.*, 1955), the

[1]To compare cost of control with the anticipated savings, our method of analysis requires estimation of (1) the rate of expected injury, (2) the relationship between injury and volume loss, (3) the relationship between injury and quality loss in residual volume, (4) the value of volume and quality saved, (5) the extent to which weevil control will reduce injury rate, and (6) the cost of applying the control measures.

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amount of weevil-caused volume loss in white pine trees now of merchantable size was estimated. It was found that, on the average, 40 percent of the merchantable volume of the present white pine in New Hampshire had been lost as a direct or indirect result of weevil-like injuries. This well-designed and carefully conducted study gives a valid estimate of current stand conditions.

Unfortunately, however, these data were not suitable for our purposes. In the first place, current stands reflect timber-cutting practices that commonly leave badly weeviled trees standing and take those less severely damaged. Obviously it would be improper to use an average loss rate, obtained in part from residual trees, to estimate what future losses might be in any particular stand. Then, too, tree volume data were separated into only two classes, weeviled and non-weeviled.

We wanted a method for estimating *future* volume losses by various *degrees* of weevil attack. Because it might be profitable to protect trees from attack only during the first log or two of height growth, our method of predicting volume loss should permit estimation of losses under such partial protection. Then again, other management practices such as thinning and release may influence the rate of weevil attack; so our method should be one that the manager can use to estimate losses for various rates of weevil attack.

Thus available data were not appropriate for the problem we had to solve; a new study was needed.

## The Study

To define the weevil-injury/volume-loss relationship,[2] we first had to identify the basic factors that control the relationship. Then, because we want to use the relationship for prediction, independent variables amenable to prediction had to be selected to reflect these basic determinants. And finally, we had to design a study to quantify these relationships.

The merchantable volume an individual white pine loses from weevil injury is determined by (1) the number of weevil injuries, (2) the height of each injury (which determines whether a high- or low-volume portion of the bole is affected), (3) the severity of each injury, that is, the length of leader destroyed (which influences the amount of deviation from normal form), and (4) the tree's age, environment, and inherent growth pattern (which define normal volume and, together with the first three factors, determine the form and amount of post-injury development).

Our approach was to determine first the actual volume, and then the unweeviled or potential volume of merchantable trees in undisturbed (unbiased) stands. Next, by regression analysis we proposed to relate the weevil-caused volume loss to independent variables that reflect the four basic determinants listed above.

The independent variables selected were (1) the number and position of weevil-like injuries and (2) the tree's d.b.h. Number and position of injuries follow directly from the first two determinants. A variable reflecting severity of injury was not included because we could not find a satisfactory way of either measuring or predicting it. D.b.h. reflects the combined effect of age, environment, and inherent growth pattern; and d.b.h. can be relatively easily measured and predicted, and usually is unaffected by the amount of weevil injury.

*Choosing sample trees.* The population to be sampled included individual white pine trees above the 8-inch d.b.h. class. A sample of 300 such pines was taken in southeastern New Hampshire. The trees, evenly distributed among 12 locations, were taken from stands that showed no evidence of past cutting or hurricane damage. Diameters (d.b.h.) ranged from 9 to 31 inches and number of weevil injuries per

[2]In this report "weevil injury" refers to all weevil and weevil-like injuries observed, although some of these may have been caused by other insects, birds, or squirrels.

tree ranged from 0 to 15.

*Estimating volume loss.* The merchantable volume lost by each sample tree was determined by subtracting actual volume from an estimate of what merchantable volume would have been if no injury had occurred.

The actual volume of each sample tree was determined by scaling diameter and estimating length and cull-percent for each log in the tree. Some trees were climbed; estimates for nearby trees were made by comparison. No trees were actually felled and bucked. A 1-foot stump was assumed, and a 6-inch d.i.b. top used as the limit of merchantability unless large branches, sweep, or crook limited merchantability below this point.

To estimate what board-foot volume would have been if no injury had occurred, three statistics were needed: "unweeviled" d.b.h., "unweeviled" form class, and "unweeviled" merchantable length. With these statistics "unweeviled" volume could be derived from Bickford's Form Class Volume Tables (Bickford, 1951).

Unless weeviling occurs below breast height, d.b.h. is probably not seriously influenced by weevil injury; therefore observed and unweeviled d.b.h. were assumed to be the same.

Total height too is not markedly influenced by weevil injury. Preliminary analysis of a subsample of the trees failed to indicate a significant relationship between number of injuries and total height in natural stands after the effect of differences in age, d.b.h., and site were removed. Perhaps the effect of weeviling is hidden in sample data by the tendency of weevils to attack the faster-growing trees more frequently. Nevertheless, for a wide range of injury intensities, the effect of weeviling on total height evidently is negligible.

Tree-form diagrams of 240 essentially weevil-free white pine trees were available from earlier volume-table studies. Using data from these diagrams, actual tree-d.b.h. and total-height measurements, and employing regression analysis, we derived estimates of unweeviled form class and unweeviled merchantable length for the sample trees.

*Expressing tree size.* To express the independent variable of tree size, "d.b.h. minus 8 inches" was used. D.b.h. was coded in this way because trees below the 9-inch d.b.h. class were assumed to have no merchantable board-foot volume.

*Expressing number and position of injuries.* The location of each observed injury was marked on a diagram of the sample tree, and the number of injuries within each 16-foot section above the 1-foot stump was determined. In the case of forked trees only the injuries observed in the dominant stem were recorded. Those injuries observed above unweeviled merchantable length were not tallied because such injuries would have no effect on recoverable volume.

Ostrander and Stoltenberg (1957) report that 80 percent of the actual weevil injuries can be detected by log-surface defects. To improve our estimate of the actual number of injuries, we multiplied the number of observed injuries in each 16-foot section by 1.25.

The precise relationship between volume-loss per injury in the butt log and in the second log, for example, depends to a considerable extent on the tree's size. If rotations are short (harvested trees small), one or more serious weevil injuries in the butt log may reduce the tree's recoverable volume to zero, whereas injuries in the second log could not possibly reduce tree volume by even 50 percent in such small trees. If rotations are longer (harvested trees larger), lower-log injuries become relatively less important. But for trees of a given size, the lower in the tree the injury occurs, the greater the associated tree-volume loss is likely to be.

We wanted to take into account the effect of this positional difference without using a different weighting system for each

*TABLE 1. Analysis of variance of the regression* $Y = 2.08X_1X_2$.

| Source | Degrees of freedom | Sum of squares | Mean square | F | Level of significance |
|---|---|---|---|---|---|
| Cross product | 1 | 3,057,889 | 3,057,889 | 557 | <1% |
| Residuals | 299 | 1,641,257 | 5,489 | ----- | ----- |
| Total | 300 | 4,699,146 | ----- | ----- | ----- |

tree size, as that would make the resulting relationship cumbersome. So the total number of injuries in each tree (regardless of size) was expressed in terms of butt-log injuries by giving injuries in the first log a weight of 1, those in the second log a weight of ½, the third log 1/3, etc. From general observation, these weights appeared reasonable for trees now being harvested. The actual number of weevil injuries in each tree, thus weighted, was calculated and termed the "injury summation." In formula form,

$$\text{Injury Summation} = \frac{\text{Injuries 1st 16 feet}}{1} + \frac{\text{Injuries 2d 16 feet}}{2} + \ldots + \frac{\text{Injuries nth 16 feet}}{n}$$

Here "injuries" refers to the actual number of weevil injuries, the observed number multiplied by 1.25.

### The Relationship

Several equation forms were tested. The form $Y = bx_1x_2$ reduced the sum of squared residuals to the greatest extent. Y is the reduction in recoverable board-foot volume, $x_1$ is d.b.h. minus 8 inches, and $x_2$ is the weevil summation. The resulting relationship was $Y = 2.08\ x_1x_2$.

This equation states that volume loss is a linear function of the product of tree size (d.b.h. −8) and the number and position of injuries (injury summation). For an injury at a particular height, absolute volume loss increases as d.b.h. increases. And for trees of a given size, the higher the injury in the tree, the less the volume loss. The regression is of course applicable only to trees which have merchantable volume, that is, to trees 8 inches and larger in d.b.h. (For smaller trees $X_1$ would be negative.)

The relationship has several interesting attributes. The variance appeared homogenous throughout the range of our data, so a weight of unity was assigned each observation. The regression coefficient b was calculated $\sum^{n}(x_1x_2y)/\sum^{n}(x_1x_2)^2$.

The cross-product was subject to several restrictions. The sample was selected so that a range of d.b.h. classes would be encountered. Thus the sample of d.b.h. is other than random and certain information normally contained in an analysis of variance was sacrificed to obtain a better estimate of the relationship of y on $x_1x_2$ for a given sample size. Also, sampling of the injury summation was subject to error and, although an adjustment was made, the possible influence of this error on the regression coefficient should be kept in mind.

When variance is calculated in the usual manner (Table 1), the standard error of the regression is

$$\text{Standard of Error of } Y = 0.088x_1x_2$$

the standard error of a single observation

$$\text{Standard of Error of } y = \sqrt{74.09^2+(0.088x_1x_2)^2}$$

and the correlation coefficient $r = +0.81$.

### Application of Results

The equation can be used for predicting the loss in recoverable volume that will result from weeviling in even-aged stands if aver-

age d.b.h. at harvest, average merchantable length at harvest, and the future occurrence of weevil injuries within merchantable length can be estimated. Average d.b.h. and merchantable length at harvest will depend on site index, stocking, intermediate stand management, and rotation age. Forest managers can estimate these from local growth studies and from their own experience.

*Estimating injury rate.* Prediction of the future rate of weevil injury may prove more difficult. With reference to the rate of injury in various portions of merchantable length, Ostrander (1957) reports that the chances of an individual tree being attacked are not influenced by the tree's height. Data taken from our 300 sample trees also indicate that in individual trees the number of injuries does not vary markedly at different heights. This means that the rate of weevil attack had been fairly constant within stands for the past 50 to 100 years; therefore, it seems safe to assume that this characteristic of weevil activity will continue in the years ahead.

Ostrander's data also indicated that the rate of injury during a tree's early life (say, from 5 to 10 feet in height) is a fairly reliable indicator of the rate of attacks it will sustain later. Thus a usable estimate of future injury rate might be the number of injuries that have already occurred. This is particularly true in stands that average 10 feet or more in height.

For very young stands, an estimatt of future injuries might be based on the injury rate in somewhat older stands of like composition nearby. Obtaining a reliable estimate of future injury rate will sometimes be very difficult, for example in stands temporarily under overstories. But more sensitive estimates of future injury rate require further research on weevil populations, the environmental factors that influence population size, and the susceptibility of white pine to injury.

*An example of prediction.* A forester is managing a stand of 20-year-old white pine. Although the stocking of white pine is rather light, he feels that by releasing some overtopped individuals he will have 100 crop trees per acre by the time the stand is harvested. He estimates that, at a rotation age, average d.b.h. will be 12 inches and average merchantable length will be 2½ logs.

From a sample of crop trees, he estimates the average weevil injury rate to be 0.15 injuries per foot. The injury summation thus is

$$X_2 = 0.15\left(\frac{16}{1} + \frac{16}{2} + \frac{8}{3}\right) = 4.0.$$

The estimate of loss in recoverable volume for the average tree will be 2.08 (12−8) (4.0) = 33 board-feet, or 3,300 board-feet per acre. This would mean that this forester could expect to lose about 40 percent of his potential net harvest volume if no weevil control measures are instituted.[3]

Could weevil control appreciably reduce this volume loss? The average height of crop trees is 13 feet. The forester has spray equipment with which he could control weevil attack until the stand reaches 30 feet in height. If he controls through the next 16 feet of height growth, injury rate will be reduced by 90 percent within this length. The adjusted injury rate for the protected section would become 0.1 (0.15) = 0.015 injuries per foot. Or looking at it in another way, protection buys a reduction in attack rate of 0.9 (0.15) = 0.135 injuries per foot for the protected section.

To calculate the potential savings in terms of yield volume we need to deal only with the protected section (12 to 28 feet above stump height) and with the reduction in attack rate (0.135 injuries per foot). Substituting reduction in attack rate for actual attack rate in the formula, savings from this particular control program are estimated at:

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[3]Estimate is based on 100 crop trees per acre, rotation of 80 years, site index 50.

Volume saved = 2.08 [12—8] [0.135 (4+12/2)]
= 11.0 board-feet per tree, or
1,100 board-feet per acre

*Other data.* Does this volume saving indicate that control can be undertaken profitably? No, this information alone is not enough. To assess profitability, one must also determine the value of this volume saved, the value saved as a result of less lumber degrade, and the cost of the control operation. Volume-loss information is only the first step in answering the problem. We are conducting additional research to estimate quality loss, the cost and effectiveness of control, and prospective white pine prices—data that are necessary before the profitability of weevil-control investments can be evaluated.

## Summary

The availability of a method of controlling the white-pine weevil in eastern white pine stands introduces a new opportunity to improve management. Procedures are needed, however, to determine whether control is conomically justified in individual stands; also to establish economic priorities for selecting stands in which control will result in the greatest saving. In order to assess the profitability of control, several categories of information are necessary, and each of these must be in a form that will allow its use in prediction.

This report describes a study dealing with the relationship of volume loss to weevil injury. The study was conducted in a manner that would yield information usable in subsequent overall analyses of control profitability, and is an example of the type of biological information useful for economic analysis and resulting management decisions.

Volume loss attributable to weevil injury was determined for each of 300 white pine trees. A regression of volume loss on tree size and the number and position of weevil injuries was then calculated. The resulting relationship was: Tree volume loss in board feet = 2.08 × (d.b.h.—8) × (injury summation).

With estimates of average tree size at harvest and anticipated frequency of weevil injuries, this equation provides estimates of volume losses that foresters can expect from weevil attack in white pine stands they are managing. Such estimates provide a partial basis for evaluating the profitability of weevil-control efforts.

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# Ceanothus Leucodermis *and Soil Nitrogen In Southern California Mountains*

BY
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JOHN M. KELLEHER

BECAUSE CEANOTHUS species are common in the mountains of southern California and because the soils in which these species grow are usually of low fertility, ceanothus-soil relationships were studied. Ceanothus species constitute a major component of the fire-type vegetation on the San Gabriel and other mountains of southern California (Horton and Kraebel 1955). The soils prevalent in the San Gabriel portion of the Los Angeles River watershed are so deficient in nitrogen that native plant growth is retarded (Hellmers *et al.* 1955a).

Results of the present study indicate that one way in which plants of chaparral whitethorn, *Ceanothus leucodermis* (Greene), improve site conditions is by increasing soil nitrogen. Recorded observations testify that plants grown close to other ceanothus species make better growth than plants associated with non-ceanothus species (Wahlenberg 1930). Quick (1944) obtained similar results in a laboratory experiment using snowbrush, *Ceanothus velutinus* (Dougl.), and gooseberry, *Ribes roezli* (Regel). Besides showing that the presence of snowbrush plants increased the growth of gooseberry plants, he demonstrated that a previous culture of snowbrush in the soil increased the survival of gooseberry seedlings. Recently Vlamis and others (1958) reported that *Ceanothus integerrimus* plants with large root nodules grew as tall in nitrogen-deficient soils as plants fertilized with nitrogen.

The roots of various ceanothus species have nodules of similar appearance (Atkinson 1892, Bottomley 1915, Hellmers *et al.* 1955b, Jepson 1936, Van Rensselaer and McMinn 1942). As described by Atkinson, the nodules originate as minute lateral abnormal growths from young roots or from the side of the large taproot. Their nodulated appearance is caused by the formation of stelar outgrowths on which the apex remains meristematic. As the nodules become older they form a loosely branched dendroid body. The new growth is lighter in color than the growth of previous years.

Internally the nodules are primarily a mass of parenchymatous cells around a woody core. Whether or not the nodules are the result of bacterial or fungal infection remains in doubt (Kelley 1950, Fred *et al.* 1932).

## Materials and Methods

Chaparral white thorn was selected for use in this study because it occurs on the major soil types of the San Gabriel Mountains. Like other species of this genus, it develops root nodules.

Subsoils of three soil types found in the San Gabriel Mountains were used. These soils were derived from the anorthosite, Lowe ganodiorite, and Wilson diorite par-

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ent rocks and are essentially undeveloped or very weakly developed. The subsoils consist chiefly of disintegrated and partially decomposed parent rock. Total nitrogen content was determined for representative samples of the soil material used.

Each of the three soil samples brought into the laboratory was thoroughly mixed to assure uniformity in the test containers. A mechanical analysis of the materials showed that the soil from anorthosite bordered between sand and sandy loam whereas the soils from both Lowe granodiorite and Wilson diorite were sands.

Thirty 1-gallon containers, 10 for each soil type, were used. One ceanothus seedling of approximately .01 gram dry weight was transplanted into each can. Three months after transplanting, the soil was inoculated with small pieces of nodules, obtained from plants in the field. At this time a single application of phosphorus (100 pounds per acre) was applied. The plants were grown in the greenhouse and given only distilled water.

Eighteen months after planting, the tops of the ceanothus plants were harvested, dried, and weighed. The nitrogen content was determined for each of the plant tops, leaving the roots undisturbed in the containers.

Tomato plants were used as test plants to determine the effect of ceanothus on the growth of other plants. Tomato seeds were planted in each of the 30 containers of soil that had previously been used to grow ceanothus. In addition, 30 containers of fresh soil of the original batch, 10 for each soil type, were planted with tomatoes. All tomato plants were harvested when they were 4 months old. Both tops and roots were collected and analyzed for nitrogen.

Preliminary tests showed nitrate nitrogen to be present in such small quantities in comparison with ammonia nitrogen that ammonia nitrogen can be considered as the total nitrogen content of the plants. Ammonia nitrogen was determined by the Nesslerization method according to the procedure of Lanni *et al.* (1945) and Miller and Miller (1948).

### Results

Tops of the ceanothus plants contained more nitrogen when they were harvested than was present in the soil mass at the time of planting (Table 1). The ceanothus increased the amount of nitrogen available in the soil not only to itself but also to the tomato plants. Grown in soil that had previously been used to grow the ceanothus and still contained the roots of the shrub, tomato plants had approximately double the nitrogen content of tomato plants grown in an equal volume of soil in

*TABLE 1. Nitrogen content of* Ceanothus leucodermis *plants, tomato plants, and three wildland soil types.*[1]

| Soil parent rock | Fresh soil (per container) | (A) Tops of *C. leucodermis* | (B) Tops plus roots of tomato plants[2] | (A) + (B) | Tops plus roots of tomato plants grown on fresh soil |
|---|---|---|---|---|---|
| | | *Milligrams of Nitrogen* | | | |
| Anorthosite | 246 | 285 ± 27.1 | 50 ± 3.4 | 335 ± 30.5 | 27 ± 1.8 |
| Lowe granodiorite | 79 | 128 ± 28.4 | 12 ± 2.6 | 139 ± 31.0 | 6 ± 1.0 |
| Wilson diorite | 112 | 175 ± 30.7 | 34 ± 5.9 | 209 ± 36.7 | 12 ± 1.0 |

[1] Ten replicas of each plant species were grown in each soil type.
[2] Soil contained roots of previously harvested *C. leucodermis* tops.

which ceanothus was not previously grown in the test.

### Discussion

The results show that one of the favorable effects of chaparral whitethorn is due to an increase of available nitrogen. The next step is to determine the method of nitrogen fixation involved. Quick (1944) has suggested, probably correctly, that nitrogen fixation is carried on in the nodules. Another possibility is that the ceanothus plants are only secondarily responsible for nitrogen fixation. By improving the soil environment, they may stimulate the development of the microflora and fauna. It is already known that many of these are capable of fixing nitrogen.

To determine what organism fixed the nitrogen will require additional studies. Techniques using isotopic nitrogen are now available (Bond 1955, Bond and Scott 1955) and through its use the pathway of gaseous nitrogen to organic nitrogen can be traced.

### Summary and Conclusion

This study has shown that plants of *Ceanothus leucodermis* on three of the soils from the San Gabriel Mountains in California markedly improved the growth of a succeeding crop of tomatoes.

At least one of the factors affected in improving the soil is an increase of available nitrogen.

*Ceanothus leucodermis* removed more nitrogen from the soil than was originally present and in addition left almost twice as much available nitrogen in the soil to be used by following crops.

Therefore, it is concluded that *Ceanothus leucodermis* is a beneficial plant in developing the mountain soil. Furthermore, this species, or an associated organism, is capable of fixing atmospheric nitrogen for plant use or the plants alter the soil conditions so as to allow this process to be carried on by soil organisms. To determine the exact agency or agencies involved requires additional studies.

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### *The De Rouen Dendro-chronograph*

Because of the need in the measurement of tree rings for a simple but durable machine, versatile enough to measure large wood specimens as well as small ones, a new dendrochronograph (Fig. 1) has been developed by the DeRouen Machine Works, Trinidad, Colorado. This development was stimulated by Herbert W. Dick, Director of the Museum, Trinidad State Junior College.

Most of the instruments used by dendrochronologists have a movable stage attached to a screw. The specimen moves while the microscope remains stationary. This tends to limit the size of wood that can be studied and increases the chances that the specimen will be disturbed while under examination. The new machine on the other hand, maintains the object in a stationary position while the microscope moves.

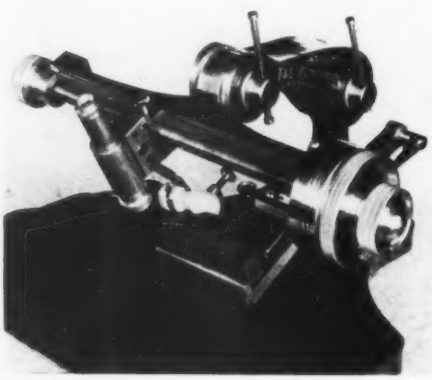

FIGURE 1. *The DeRouen dendro-chronograph used in measuring tree rings.*

The frame of the DeRouen instrument is adjustable in any horizontal position by double, nonslip joints. These facilitate ease in viewing and object. The machine is mounted on a polished hardwood base 24 x 24 inches square and 1½-inches thick. The height of the aluminum frame is 9½ inches above the top of the base. The length of the adjustable frame member, from front to back, is 20 inches. The microscope carriage has a total overall length of 25¼ inches.

The screw upon which the microscope mount moves is 18 inches long. A Vernier scale on the carriage, marked off in 440 continuous divisions with each centimeter line numbered, aids in cross checking the running length of measurements recorded from the millimeter wheel.

The microscope moves along the screw from left to right by turning the large knurled millimeter measurement wheel on the right side of the carriage. The wheel measures 4-7/8 inches in diameter. The surface is divided into 100 lined units with every tenth unit numbered. The wheel allows readable measurements to 0.01 mm. For each measurement the wheel has an automatic stop for a quick return to zero for the next measurement. Measurements of one mm are signaled by a sounding device on the wheel.

The microscope can be moved into any position along the screw by disengaging the nut on the microscope mount. The microscope mount is held rigid when engaged by a double inset track on the carriage. A light is attached directly to the microscope mount and moves with it.

The price of the machine is $450 F.O.B. Trinidad, Colorado, less microscope.

# *Relation Between Site Indexes of Eastern White Pine and Red Maple*

BY
RALPH W. FOSTER

EASTERN WHITE PINE (*Pinus strobus* L.) is a species that has amply demonstrated its potentialities on abandoned agricultural lands in the hills of New England and New York. The vigor of hardwood competition on the moist and relatively fertile glacial tills that predominate has tended to discourage attempts to maintain the species beyond the first old-field generation (Lutz and Cline, 1947). Although silvicides make it possible to overcome many of the difficulties formerly encountered, it remains necessary that investment in hardwood control be guided by knowledge of the potentialities of different sites for growth of white pine. The lands are so accessible that heavy cutting has virtually eliminated dominant white pines from much of the land. The use of direct measurement of white pine site index for evaluating site quality is thus often precluded, even though most of the land is now covered with forests.

This investigation was undertaken to seek an alternative measure of the quality of these sites for growing white pine. A more general objective was to test the hypothesis that site index of one species could be used to predict site index of another species if it were established on a particular site.

### Past Work

There are two general approaches to the problem of evaluating site quality when the desirable tree species in question is absent. The most common method is to express site quality in terms of basic environmental factors associated with tree growth. Such factors can be classified as edaphic, biotic, or climatic. The second approach is to use vegetation as a measure of site quality. The use of indicator plants to delineate differences in site quality is an example.

Coile (1948), and Coile and Schumacher (1953), reviewed the literature concerning early investigations of site quality classification based on environmental factors conducted in North America. Subsequent to Coile's investigation in the Southeast, other investigators have used similar techniques to express site index in terms of certain environmental factors throughout most of North America. The results have varied according to the nature of the critical environmental factors in different regions. The techniques employed have laid great stress on semi-permanent site factors, especially physical properties of the soil and climatological averages.

Several different site-quality classifications have been developed for eastern white pine. Most of the early classifications were very general, dividing particular areas into site-quality classes, usually three in number.

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The author was, until his death on February 3, 1959, Assistant Forester on the staff of the U. S. Forest Service at the Savannah River Project, Atomic Energy Commission, Aiken, South Carolina. This paper was submitted shortly before his death and is part of a dissertation presented in 1958 for the degree of Doctor of Philosophy in Yale University. Minor revisions have been made by Prof. D. M. Smith under whose direction the work was done.

These classifications were generally based on such factors as origin of parent material, topographic situation, and certain soil properties (Cline and Lockard, 1925; McKinnon *et al.*, 1935; and Donahue, 1936).

Gaiser and Merz (1953) investigated the rate of growth of white pine trees planted on old fields in the unglaciated regions of Ohio and central Indiana. They found that, of all the factors observed, the thickness of the A horizon showed the strongest relation with the height growth of white pine trees. The thicker the A horizon, the higher were the site-index values of the pine. They also reported that the texture and moisture equivalent of the soil were also related to variations in site index.

Young (1954), in a preliminary investigation in Maine, found that the site-index values of white pine trees were related to the thickness of the A horizon and the percentage of the surface occupied by stones. He noted that as the thickness of the A horizon increased, the site-index values of the white pine trees decreased, in contradiction to the conclusion of Gaiser and Merz (1953).

Husch and Lyford (1956) in their study in New Hampshire concluded that soil drainage classes were significantly related to the height growth of white pine trees. They found that as soil drainage became increasingly impeded, the height growth of white pine trees increased.

Heimberger (1934) used minor vegetation to classify the Adirondack Mountain region of New York into 22 forest types. Hazard (1935) adapted Heimberger's technique of classifying forest types in white pine stands in southern New Hampshire. She classified the various sites into five types and five subtypes, all based on the indicator vegetation of the forest floor.

Clements (1928) emphasized that the entire plant community indicates site quality. He stated that dominant tree species as well as understory vegetation should be examined before preparing a site classification. Coile (1948) compared site indexes of loblolly and shortleaf pine growing in association on sites located in the southern Piedmont of North Carolina, and presented equations predicting site index of each species in terms of the other. He reported that within the range of site conditions investigated, site index values for loblolly pine trees were higher but consistently related to those of associated shortleaf pines.

Einspahr and McComb (1951) compared site indexes of eastern white pine trees and associated oak trees in northeastern Iowa. They reported that at the end of 50 years, white pine trees had, on the average, grown eight feet taller than associated oak trees. The greatest difference between the height growth of the two species occurred on the poorest sites.

The most intensive study of the height-growth relationship between dominant tree species growing in association has been described in a preliminary report of the Southeastern Forest Experiment Station (1954). A comparison of site indexes of 10 different tree species growing on the same land in the southern Appalachian Mountains was presented graphically. It was reported that with one exception white pine trees at age 50 were superior in height growth to the nine other species tested. On the best sites yellow popular (*Liriodendron tulipifera* L.) did exceed the height of the white pine; it was also the species most responsive to site changes. No statistical evidence was included to evaluate the reliability of using site index of one species to predict that of another.

### Scope and Objectives of This Investigation

The specific objective of the present study was to determine the relation between site index of eastern white pine and site index of red maple (*Acer rubrum* L.) growing on the same soils. If a good relationship were established, then, site index of white pine could be predicted from that of red maple. This species was selected because it very commonly occurs in association with white pine and is also present in many areas

lacking white pine.

In designing an experiment to test this hypothesis the following restrictions were imposed.

1. The study region was geographically limited to a locality in which there was little variation in the nature of bedrock, macroclimate, and latitude.
2. All sample plots were located on soils derived from glacial till. The main category of soils avoided were those derived from glacial outwash.
3. Sample plots were not established on soils principally derived from sedimentary rocks.
4. Only old-field stands of the first generation were sampled.
5. The sample trees met rigid specifications to ensure that they accurately reflected true site index. The requirements included the following specifications:
   a. Red maple and white pine sample trees were dominant or codominant and had been so throughout their lives.
   b. The paired sample trees were located within rather than along the edges of areas of seemingly uniform site characteristics and were within 50 feet of each other.
   c. The paired sample trees were located in even-aged stands whose average ages ranged between 40 and 60 years.
   d. Neither open-grown stands nor stands that showed evidence of stagnation were sampled. However, some sample plots were established in stands that had been partially cut.
   e. White pine sample trees had not been subjected to significant injury by the white pine weevil (*Pissodes strobi* Peck). No more than four visible weevil or weevil-like injuries per stem were allowed.
   f. Red maple sample trees were of seedling origin; those originating from stump or seedling sprouts were excluded.

A second objective of this study was to determine the relation between certain environmental factors and the site indexes of white pine without reference to red maple. Part of the purpose was to compare the merits of this approach to the prediction of site index with that in which the growth of red maple was used as an integrating indicator of the site factors. The data obtained also provided a means for testing a predictive mechanism that combined both approaches.

Eleven soil and physiographic factors were measured to test these relationships: elevation, percentage of slope, position on slope, shape or curvature of slope, aspect, thickness of A horizon, depth to a compact layer or depth of effective rooting, and several characteristics of the upper six inches of the mineral soil, viz., percentage of sand and clay separately, moisture equivalent, and soil reaction. A twelfth characteristic, the product of moisture equivalent and depth to a compact layer, or that of effective rooting, was also determined from appropriate computations.

Finally, the relation between the height and age of the two species was determined by stem analysis for each sample tree.

### Description of the Region

The area first selected for study was located between the Housatonic and Connecticut Rivers in extreme northwestern Connecticut and western Massachusetts. As the field work progressed, it became apparent that sufficient sample plots could not be conveniently located within this area. Furthermore, the initial exploratory work indicated that variations due to differences in geographic location was small. Additional sample plots were accordingly established at the Yale Forest near Union in northeastern Connecticut, and in Warren County in eastern New York.

Almost all the sample plots were located on soils belonging to the brown podzolic soil group but a few, chiefly at higher elevations, were located on true podzols.

The investigation was deliberately confined to a region of relatively uniform climate in order to eliminate the kind of variance in results that might come from major differences in regimes of temperature and precipitation. The mean annual precipitation in the region of the study varies between 40 and 50 inches and that of the

months from May through August, between 14 and 18 inches. The mean length of the growing season varies from 120 to 160 days.

Although the study region was located within the natural range of white pine and red maple, in northwestern Massachusetts and in Warren County, New York, very few white pine trees were observed growing at elevations exceeding 2000 feet. At this elevation red spruce (*Picea rubens* Link) generally occupies sites that are apparently similar to those where white pine occurs at lower elevations.

### Identification of Red Maple Trees of Seedling Origin

Red maple trees of seedling-sprout origin exhibit different growth rates and forms from those of seedling origin (Leffelman and Hawley, 1925). A separate minor study was conducted in order to establish a reliable means of distinguishing the two growth forms.

Three distinguishing characteristics were observed. The initial height growth of seedling sprouts in all cases was greater than that of maples of seedling origin. The average seedling sprout attains a height of 10 feet in five years but a seedling takes 11 years. Initial diameter growth of seedlings and seedling sprouts was noticeably different. The widths of the first few annual rings of the seedling sprouts exceeded those of even the fastest growing seedlings. Finally, the shape of the base of the red maples in many instances aided in distinguishing between trees of seedling and seedling-sprout origin. Red maple seedlings normally develop into trees that are straight and radially symmetrical throughout the lower portion of the bole. The bases of red maples originating from seedling sprouts, however, are normally crooked or asymmetrical, often having a pronounced sweep just above the ground line.

In order to reduce statistical variation and thereby increase the usefulness of red maple for predicting white pine site index, only trees of seedling origin were used in the study.

### Collection of Data

*Field methods.* Records maintained by various public foresters for control of blister rust and other purposes were used for locating most of the promising areas for sample plots. No attempt was made to allocate plots in equal numbers to the various categories of any preconceived classification of environmental factors. Instead, an attempt was made to locate plots representing the widest possible range of site index of white pine growing on soils derived from glacial till. Plots consisting essentially of paired sample trees of the two species were established wherever such pairs could be found that met the stated requirements.

After a plot had been selected for analysis, data on height and age were gathered for each of the paired sample trees by stem analysis techniques. Each red maple was felled and bucked into 8- or 10-foot sections depending upon the total height of the tree. Ring counts were made on the stump and on the lower end of each of the bolts.

Because of the reluctance of owners to allow pines to be felled and sectioned, stem analysis on white pine was performed on standing sample trees. Branch whorls were counted from the base upwards to determine the age of trees at different heights. The virtually complete failure of natural pruning, which is characteristic of white pines of the age of the sample trees, made it entirely feasible to detect the annual branch whorls. An Abney level was used to determine the actual height above ground at various points on the stem.

The total ages of sample trees of both species were determined by counting annual rings at a stump height of one foot and adding the average number of years required for seedlings to attain that height. The ring counts were made on the stumps of the red maples and from increment borings in the white pines. Eighty young seedlings of each species were examined on several old fields in various parts of the region of the study to establish the average

number of years they required to grow to a height of one foot. This was found to be 3 years for red maple, with values ranging from 2 to 4 years; for white pine the average was 5 years with a range of 4 to 7 years.

Measurements of the physiographic factors were then recorded. Elevation in feet was determined from topographic maps of the U. S. Geological Survey. Steepness of slope was measured in percent with an Abney level. Aspect was recorded in azimuth from hand compass bearings. Position on slope was estimated visually with the aid of topographic maps and was recorded as a percentage of the distance between the top and bottom of the slope. The shape or curvature of the slope was estimated visually and was recorded as convex, slightly convex, uniform, slightly concave or concave. The distance and direction of the location of the red maple sample trees from those of pine were recorded.

One soil pit was excavated on each plot. Wherever possible the pit was located between two study trees. The depth of the pit was determined by the location of the compact layer or, in its absence, by the depth of effective rooting which in some cases was three feet. Measurements were made on each side of the pit and the average of the four values was recorded for each of the following characteristics: thickness of unincorporated humus layer, thickness of the $A_1$ and B horizons, and depth to a compact layer or depth of effective rooting. The soil reaction on the top six inches was determined by a Hellige-Truog soil reaction kit. The principal reason for determining pH in the field was to detect soils derived from parent material chiefly of limestone and to exclude such sites from the investigation. Finally, a soil sample from the top six inches was collected for laboratory analysis.

*Laboratory methods.* In the laboratory the soil samples were air dried and passed through a two-millimeter sieve. Soil texture was evaluated by the Bouyoucos (1951) hydrometer method. Moisture equivalent values were determined by means of a centrifuge following the method of Veihmeyer *et al.* (1924). The pH of each sample was measured with a Beckman potentiometer and these values, rather than those measured in the field, were used in the statistical analyses.

### Relationships Between Height and Age

Curves representing the relation of height to age were fitted by hand to the plotted data for each of the 142 sample trees. In 54 instances where the total age of pine or maple sample trees was less than 50 years, the curves of height over age were extrapolated so that values of site index at 50 years could be obtained. The method of extrapolation (Root, 1927) was based on Newton's binomial interpolation formula with backward differences, an entirely mathematical and objective technique. Extrapolations to age 50 over periods longer than 10 years were necessary for 7 trees.

Figure 1 shows the average curve of height over age for each species for the first 60 years. The graph indicates that, during

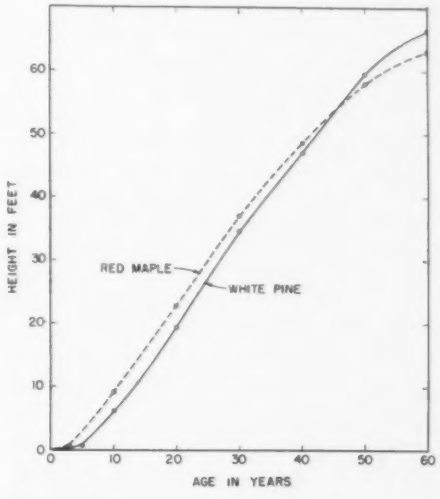


FIGURE 1. *Average curves of height over age for 71 red maple and 71 white pine sample trees.*

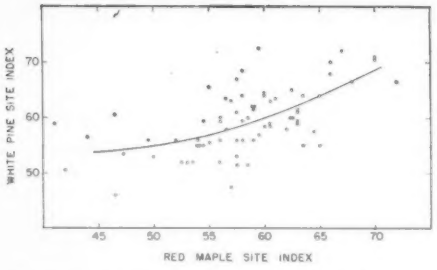


FIGURE 2. *Relation between site index values of the white pine and red maple sample trees. The curve represents the equation of white pine site index in terms of red maple site index.*

the early stages of development, the average rate of height growth of red maple seedlings is superior to that of associated white pine seedlings. Red maples of seedling origin maintain this advantage in height growth for several years. During middle age or, according to the data at hand, near age 46, the height of white pine trees equals and commences to surpass the height of associated red maples. In later years white pine trees normally increase their height advantage over associated maples.

Having determined the site index value for each sample tree, it was noted that the range of values for white pine was only 27 feet; the lowest value was 46 and the highest 73. This range compares favorably with that reported by Frothingham (1914) in normal yield tables for white pine. Although this range appears to be narrow, Frothingham's yield tables indicate that an increase of one foot in site index is associated with an increase of approximately 200 cubic feet per acre in the volume of an 80-year-old stand of white pine. Therefore, a small difference in site index represents an important difference in total volume production.

### Prediction of Site Index of White Pine

*Prediction from site index of red maple and site factors.* After determining site-index values for all sample trees, the values for white pines were plotted over the corresponding values for red maple and over values representing each of the 11 environmental factors. From an inspection of these graphs it was apparent that red maple site index (Fig. 2) was the single variable most strongly correlated with white pine site index.

A multiple regression analysis was used to determine the relation between the site-index values of the white pine and red maple trees. The results of this regression were tested by means of the "F" test of significance (Table 1). This test indicated that the regression was significant at the 1 percent level, thus demonstrating a highly significant relationship between site indexes of these species. The "F" test indicated that this relationship was slightly curvilinear.

An equation was developed expressing site index of white pine in terms of that of red maple. The values for white pine site index (WPSI )and red maple site index (RMSI) were coded by multiplying by 10. The equation is as follows: $WPSI = 892.99 - 1.6581\ RMSI + .0019486\ RMSI^2$. This equation demonstrates the relationship between the two species. The standard error of estimate for this equation was 7.6 percent and 39.2 percent of the total variation about the mean of the white pine site-index values was explained by this relationship.

The curve in Figure 2 shows this relationship between site indexes of the two species. On sites that were average or poorer, the height of the pine sample trees at 50 years was superior to that of the red maples growing in association with the pines. On the best sites the height of the maple sample trees at 50 years was greater than that of associated pine trees. This relationship indicates that red maple is apparently more sensitive than white pine to changes in site quality. The Southeastern Forest Experiment Station (1954) reported a similar relationship between white pine and yellow-poplar in the southern Appalachian Mountains. Although the site-in-

*TABLE 1. Analysis of variance of the regression of white pine site index on red maple site index.*

| Variable | Degrees of freedom | Sums of squares[1] | Mean squares | F values |
|---|---|---|---|---|
| RMSI | 1 | 81,561 | 81,561 | 39.344** |
| RMSI[2] | 1 | 9,229 | 9,229 | 4.452* |
| Regression | 2 | 90,790 | 45,395 | 21.898** |
| Residuals | 68 | 140,985 | 2,073 | |
| Total, about mean | 70 | 231,775 | | |

[1]Sums of squares were computed from the basic site-index values for white pine.
**Significant at the 1 percent level.
*Significant at the 5 percent level.

*TABLE 2. Analysis of variance of the regression of white pine site index on red maple height, red maple age, and aspect.*

| Variable | Degrees of freedom | Sums of squares[1] | Mean squares | F values |
|---|---|---|---|---|
| Red maple height | 1 | 6,425 | 6,425 | 6.196* |
| Red maple age | 1 | 43,289 | 43,289 | 41.744** |
| Aspect | 1 | 4,194 | 4,194 | 4.044* |
| Regression | 3 | 53,908 | 17,969 | 17.329** |
| Residuals | 67 | 69,467 | 1,037 | |
| Total, about mean | 70 | 123,375 | | |

[1]Sums of squares were computed from the basic site-index values for white pine.
**Significant at the 1 percent level.
*Significant at the 5 percent level.

dex values indicated that site quality for white pine was generally higher there than in the region of this investigation, it was reported that yellow-poplar trees were more sensitive to changes in site quality than were white pine trees. Einspahr and McComb (1951) indicated that oak was also more sensitive to changes in site quality than was associated white pine.

After determining the basic relation between the site indexes of the two species, the values that had been worked out for each of the 11 environmental factors (listed previously) were tested to ascertain whether any of them differed significantly in their relationship to the site index values of each species. If any of these factors did have a different relationship to one species than to the other, then their inclusion in the equation would increase the predictive usefulness of measurements of site index of red maple for expressing that of white pine. The "F" test showed that only aspect differed in its relation with the two species; this difference was just significant at the 5 percent level (Table 2).

A new equation was developed incorporating the added effect of aspect to the relation between site indexes of red maple and white pine. Unlike the first equation in which red maple site index was used directly, in this equation red maple site index is expressed in terms of red maple height and age. Statistical analysis showed that this second method of expressing site index gave virtually the same result as was

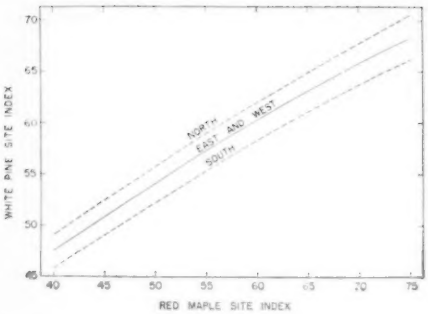


FIGURE 3. *Graphical representation of the equation predicting white pine site index in terms of aspect and red maple height and age.*

obtained by using red maple site index directly. Thus, by using the red maple height and age measurements, the necessity of computing site index values for the species was eliminated. In this equation white pine site index (WPSI) and red maple height (RMHt) were expressed in logarithms of feet; red maple age was measured in years; and aspect was measured in azimuth with the values coded as follows:

| | |
|---|---|
| South | 0 |
| SSW and SSE | 10 |
| SW and SE | 20 |
| WSW and ESE | 30 |
| West and East | 40 |
| WNW and ENE | 50 |
| NW and NE | 60 |
| NNW and NNE | 70 |
| North | 80 |

The equation is as follows:

$$\text{Log WPSI} = .57263 + .56506 \text{ Log RMHt} + \frac{9.4025}{\text{RM Age}} + .00039144 \text{ Aspect.}$$

This equation accounted for 43.7 percent of the total variation about the mean of the white pine site-index values and the standard error of estimate was 7.7 percent.

The effect of aspect on predictions of white pine site index from this equation is illustrated in Figure 3. The two broken lines indicate the magnitude of the influence that differences in aspect have on white pine site index. The effect of northerly aspects is to increase the expected site-index values of white pine, and, of southerly aspects, to decrease them.

None of the remaining factors differed significantly in the kind of relationship that they bore to the site-index values for the two species. The absence of appreciable differences between the effects of particular measurable factors of the environment makes it difficult to increase the predictive accuracy of an equation in which red maple site index and aspect are used as independent variables. Furthermore, this lack of differences indicates that most environmental factors affect the two species in the same general manner and that the height growth of red maple represents a useful means of integrating the factors that control the height growth of pine.

Attention was then turned to the determination of differences in the shapes of the various curves of height over age that might influence the accuracy of prediction of white pine site index from that of red maple.

Inspection of the curves of the height over age for white pine indicated strongly that only one general form of curve was represented, but there appeared to be some tendency for the curves for red maple to vary slightly in form. Some ascended more rapidly at the lower end than the average curve shown in Figure 1; others tended to level off earlier at the upper end of the curve. However, statistical analysis showed that differences in the shapes of the red maple growth curves did not significantly influence the proposed method of predicting site index of white pine.

Certain field observations afford a partial explanation for the variation in the form of the red maple curves. In a few cases red maple and white pine sample trees had been growing crown-free for sev-

eral years as a result of previous partial cuttings. While the pine trees continued to increase in height in a normal pattern following the cuttings, the height growth of some of the red maples was reduced. It appeared that the crowns of these particular red maples grew outward rather than upward. These observations may bear some relationship to the findings of Gaiser and Merz (1951) that stand density influenced the height growth of white oak in southern Ohio. They showed that white oak trees in open-grown stands were not as tall as those growing in dense stands on similar sites.

Another factor which might contribute to the variation in the curves of height over age for certain red maple trees is ice damage. Downs (1938) reported that red maple trees in Pennsylvania had suffered extensive damage from a glaze storm. He observed that white pine trees, growing in the same region where the red maples had been injured, had suffered very little damage. Glaze storms have occurred within the study region and have caused varying amounts of damage to standing trees. While an attempt was made to exclude such trees from the sample, it was not always possible to detect damage that may have occurred.

*Prediction from site factors alone.* The next analysis was designed to test the relation between the white pine site-index values and the 11 environmental factors by means of multiple regression without reference to the data on red maple.

Although the "F" test indicated that this regression was significant at the 1 percent level, the relation was rather weak. All 11 variables accounted for only 36.5 percent of the total variation about the mean of the white pine site-index values, and none of the variables showed a very strong relation with these site-index values. Of the 11 variables, the depth of the $A_1$ horizon, position on slope, and the depth to a compact layer were significant between the 5 percent and 1 percent level. None of the remaining variables used in this regression was significant at the 5 percent level.

The five variables that contributed the greatest amount to the sums of squares due to the regression, namely, depth to a compact layer, depth of the $A_1$ horizon, elevation, position on slope, and moisture equivalent were tested in an additional multiple regression analysis (Table 3). The "F" test indicated the relationship between white pine site index and these variables was just significant at the 1 percent level and that only 30.8 percent of the total variation about the mean of the white pine site-index values was explained by this regression.

The interpretation of the relationship between site index of white pine and the several environmental characteristics is obscured by many factors. The strength of a relationship is in part dependent upon the observed range of values of both the dependent variable and the independent variables. The range of white pine site-index values was only 27. This is narrow compared to the range in site-index values of 54 reported by Doolittle (1957) for scarlet and black oak.

The range of variation in any particular site characteristic must also be considered when interpreting the correlation between the characteristic and site index. This point comes to issue in the case of the finding, both in this study and that of Young (1954), that site index of white pine decreased with increasing thickness of the $A_1$ horizon. Actually, this thickness was found to vary almost entirely between three and seven inches and the narrowness of this range leads to some doubt as to the biologic importance of the correlation even though it is statistically significant. The weakness of the relation between the thickness of the $A_1$ horizon and the values of site index is illustrated by the graphical representation in Figure 4.

In spite of its weaknesses, the regression equation (Table 3) predicting white pine site index in terms of the five environmental factors leads to one general conclusion. It shows that the site-index values of white

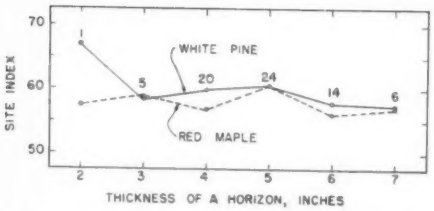


FIGURE 4. *Relation between average site index values of red maple and white pine sample trees and thickness of the $A_1$ horizon. The numeral above each point represents the number of measurements upon which that point was based.*

pine increase as (1) the thickness of the $A_1$ horizon decreases, (2) the elevation decreases, (3) the position on slope becomes lower, (4) the depth to a compact layer increases, and (5) the moisture equivalent increases. With the exception of the effects of depth of the $A_1$ horizon and elevation, the equation supports the contention that as the ability of the site to supply water increases, the site quality for growing pine increases. This view is supported by the results of Husch and Lyford (1956) who concluded that, within limits, as soil drainage became increasingly impeded, the height growth of white pine increased.

The use of these environmental factors without reference to the site index of red maple did not provide a means of predicting site index of white pine as good as that involving the use of height and age of red maple and aspect. Regression of all 11 environmental factors on site index of white pine accounted for 36.5 percent of the variation; that of the five most significant of these factors, for 30.8 percent. Furthermore, none of these five variables taken in-

*TABLE 3. Analysis of variance of five variables and the product of moisture equivalent and depth to a compact layer on white pine site index.*

| Variable | Degrees of freedom | Sums of squares | Mean squares | F values |
|---|---|---|---|---|
| Depth of $A_1$ horizon | 1 | 11,628 | 11,628 | 4.592* |
| Elevation | 1 | 12,469 | 12,469 | 4.925* |
| Position on slope | 1 | 9,188 | 9,188 | 3.629 |
| Depth compact layer | 1 | 10,672 | 10,672 | 4.295* |
| Moisture equivalent | 1 | 3,510 | 3,510 | 1.386 |
| (ME) (CL) | 1 | 23,575 | 23,575 | 9.311** |
| Residuals | 63 | 159,495 | 2,532 | |
| Total, about mean | 69 | 230,537 | | |

*Significant at 5 percent level.
**Significant at 1 percent level.

The regression equation is:

WPSI = 399.04 − .040996 Depth $A_1$ Horizon − 4.6772 Elevation + 1.6385 Position on Slope + 11.017 Depth to Compact Layer + 1.3871 Moisture Equivalent − 6.2142 (ME) (CL)

Where:

(1) Depth $A_1$ Horizon measured in inches, coded by multiplying by 10.

(2) Elevation measured in feet, coded by dividing by 10.

(3) Position on slope expressed as a percentage of horizontal distance between top and bottom, coded into 5 groups.

(4) Depth to compact layer (or depth or rooting) measured in inches, coded by multiplying by 10.

(5) Moisture equivalent values coded by multiplying by 10.

(6) (ME)(CL) is uncoded product of moisture equivalent and depth to compact layer (or depth of rooting), being a measure of the water-storage capacity of the stratum of rooting; it acts as a negative term modifying the equation because the main effects of the two variables were accounted for separately.

*TABLE 4. Predicted values for white pine site index from red maple height, red maple age, and aspect.*[1]

| Age | Red maple height (feet) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (years) | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 |
| 30 | 43 | 49 | 54 | 59 | 64 | 68 | 72 | 76 | 80 | 84 | 87 | 90 |
| 35 | 39 | 44 | 49 | 53 | 57 | 61 | 65 | 69 | 72 | 76 | 79 | 81 |
| 40 | 36 | 41 | 45 | 49 | 53 | 57 | 60 | 63 | 67 | 70 | 73 | 75 |
| 45 | 34 | 38 | 43 | 46 | 50 | 54 | 57 | 60 | 63 | 66 | 69 | 71 |
| 50 | 32 | 37 | 41 | 44 | 48 | 51 | 54 | 57 | 60 | 63 | 66 | 68 |
| 55 | 31 | 35 | 39 | 43 | 46 | 49 | 52 | 55 | 58 | 61 | 63 | 66 |
| 60 | 30 | 34 | 38 | 41 | 45 | 48 | 51 | 53 | 56 | 59 | 61 | 64 |
| 65 | 29 | 33 | 37 | 40 | 43 | 46 | 49 | 52 | 55 | 57 | 60 | 62 |
| 70 | 29 | 32 | 36 | 39 | 42 | 45 | 48 | 51 | 53 | 56 | 58 | 60 |
| 75 | 28 | 32 | 35 | 38 | 41 | 44 | 47 | 50 | 52 | 55 | 57 | 59 |
| 80 | 27 | 31 | 35 | 38 | 41 | 43 | 46 | 49 | 51 | 54 | 56 | 58 |

[1]Add 3.5 percent of the white pine site index value for northerly aspects. Subtract 3.5 percent of the white pine site index value for southerly aspects. Use table directly for easterly and westerly aspects.

dividually showed a very strong relation with white pine site index. On the other hand, the regression of white pine site index on that of red maple accounted for 39.2 percent of the variation and the conversion of red maple site index to an expression involving height and age directly, as well as the incorporation of aspect as an additional independent variable, increased this proportion to 43.7 percent.

A more obvious difference in the applicability of the two methods is recognized when field application is considered. Only aspect and the total height and age of red maple trees need be measured to evaluate white pine site index when red maples are used as indicators of site quality. With this information, the site index of white pine can be determined from Table 4. The use of this method is, of course, dependent upon the presence of dominant red maples of seedling origin. The ease of application is self-evident. On the other hand, use of environmental factors alone would require time-consuming field and laboratory techniques to measure the necessary characteristics. This information must then be substituted into an equation for predicting white pine site index in terms of the five environmental factors. Upon completing this laborious task the results of this method would still not be as accurate as those based on the use of red maple trees.

### Summary and Conclusions

A comparison was made between site indexes of associated white pine and red maple trees growing on soils derived from glacial till in eastern New York, western Massachusetts, and northeastern and northwestern Connecticut. The purpose of this investigation was to determine whether red maple trees would be useful indicators of the site quality for growing pine in situations where pine site index could not be determined directly.

Site characteristics were measured and site-index data were collected from sample plots consisting of paired white pine and red maple trees. Criteria for distinguishing red maple trees of seedling origin from those of seedling-sprout origin were established. By restricting observations to maples of seedling origin, the variation in the curves of height over age was substantially reduced; adherence to such restrictions is essential to successful application of the method of prediction here proposed. Slight

variations observed in the form of the curve of red maple height over age were found to have no important effect on the accuracy of the technique. Such curves for white pine were found to exhibit one general form.

The relation between site indexes of these two species and 11 different site characteristics were tested in a multiple regression analysis. A significant relationship was established between site indexes of red maple and white pine. On sites that were average or poorer, the height of white pine sample trees at 50 years was superior to associated red maples. On the best sites, the height of red maple sample trees at age 50 was greater than that of associated pine trees. In regard to the site characteristics only aspect differed in its relation with the two species. The effect of northerly aspects is to increase the expected site-index values of white pine over maple, and, of southerly aspects, to decrease the expected site-index values of white pine. An equation was developed predicting pine site index in terms of red maple height, red maple age, and aspect.

This method of determining white pine site index was compared with that of assessing site index of pine in terms of 11 site characteristics without reference to red maple. Multiple regression analysis indicated a significant relation between site index of white pine and these site characteristics. However, the regression of all 11 of them did not account for as much variation in the white pine site-index values as the variation explained by using red maple as an integrating indicator of the totality of site factors. Furthermore, the field use of the site characteristics was cumbersome and the results were less accurate than those obtained by using red maple trees to assess the site quality of white pine.

Finally, there was a narrow range in the site-index values of white pine within the region sampled. This limited variation in the dependent variable reduces the opportunity to develop techniques for predicting differences in white pine site index from measured site characteristics.

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Leffelman, L. J., and R. C. Hawley. 1925. Studies of Connecticut hardwoods. The treatment of advance growth arising as a result of thinnings and shelterwood cuttings. Yale Univ., Sch. of Forestry Bul. 15. 68 pp.

Lutz, R. J., and A. C. Cline. 1947. Results of the first thirty years of experimentation in silviculture in the Harvard Forest, 1908-1938. Harvard For. Bul. 23. 182 pp.

McKinnon, F. S., G. R. Hyde, and A. C. Cline. 1935. Cut-over old field pine lands in central New England. Harvard For. Bul. 18. 80 pp.

Root, R. E. 1927. The mathematics of engineering. Williams and Wilkins, Baltimore. 540 pp.

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## *The Physiology of Forest Trees*

*Edited by Kenneth V. Thimann with the assistance of William B. Critchfield and Martin H. Zimmerman. The Ronald Press, New York. 678 pages. $12.00.*

*Review by John P. Decker*

*U. S. Forest Service, Arizona State College, Tempe, Arizona*

A symposium held at Harvard Forest in 1957 under the auspices of the Cabot Foundation is summarized in this book. Each chapter is a review of a currently active field of research in tree physiology written by an active worker in that field.

Not intended as an introductory text, the book makes no attempt to give an overall view of all known tree mechanisms. It is an advanced work that should save much time and effort for those whose research duties or interests include analysis and explanation of certain problems of tree behavior.

Several of the 35 chapters do not have summaries—a conspicuous lack when one is trying to screen rapidly—and two were evidently written before the authors had formulated clear statements of the problems involved. These faults are minor, however, in the light of the large task accomplished by the book—that of bringing another section of the current landslide of literature under useful control.

Per F. Scholander gives in Chapter 1 a new treatment to the old familiar cohesion theory of water movement in trees. He postulates a continuous system in which water moves at times principally in high-resistance

micropores and at times principally in low-resistance macropores. He presents convincing experimental evidence in support of his theory.

Because the author of this chapter, an M.D., as well as a Ph.D., is not well known to plant scientists, a few personal notes may be in order. His several, brilliantly simple, analytical instruments are well known to animal and medical physiologists. Major Scholander's long list of important contributions to the USAAF's program of aviation physiology during World War II made him seem almost legendary to those who did not have the privilege of knowing him personally. As an intensely interested scientist who happened to be in uniform and to whom "rank" meant little, he was a delightful and inspiring leader to those of us who served with him, but his sensible and direct approach to problems (both technical and administrative) was often a bane to officious "brasshats." That same clear-minded approach is evident in Chapter 1.

Other chapters by many different authors cover a wide range of subjects. Kenneth N. H. Greenidge discusses the extensive work on injection and movement of dye solutions in trees that started as a result of interest in birch dieback. Results of these studies lead him to a concept of the water-conducting system of large trees that is consistent with Scholander's micropore-macropore theory for smaller woody plants. R. Darnley Gibbs in summarizing the results of 20 years of studies on seasonal changes of water content of trees in eastern Canada finds that these "show surprising differences in their behavior, differences that are puzzling—to the writer, at least." Irving W. Bailey discusses anatomy of tracheids with traditional speculative consideration given to operational mechanics. Edward G. Bollard after revewing the analyses of xylary fluid concludes that in some trees the leaves receive little or none of their nitrogen in the form of nitrate but rather in the form of organic compounds synthesized by the root systems. James W. Marvin discusses historical and recent information about the characteristics and probable mechanisms of maple sap flow. Edward C. Stone covers work on the controversial subject of direct absorption of dew by shoots. He concludes that prolonged survival in dry soil of plants that are subjected to artificial dew results from direct rehydration of leaves rather than from transfer of water back into soil. Paul J. Kramer gives a thorough review of silvical aspects of photosynthesis. His final paragraphs may partially disenchant those who are bedazzled into thinking that photosynthesis is a silvical panchreston.[1]

Bruno Huber discusses briefly some problems involved in using an infrared gas analyzer in field studies of photosynthesis and Frederick H. Bormann the successional implications of changes of photosynthetic response of loblolly pine seedlings with age and shade.

Discussed in Chapters 11 through 14 are biochemical processes in the bark of black locust by David Siminovitch and A. P. J. Chater; taxanomic aspects of turpentine in pine by Nicholas T. Mirov and taxomomic aspects of ligin by R. Darnley Gibbs. Philippe F. Bourdeau and Clifford S. Schopmeyer conclude that ratio of oleoresin pressure to viscosity may be a useful index in selecting and breeding high-yielding slash pine.

In Chapter 15, Leonard Leyton concludes that the relationship between mineral content of foliage and growth of conifers is not yet well enough defined to be of much use, and in Chapter 16, Donald A. Fraser reports early stages of work on movement of radioactive salts in trees.

In Chapters 17 through 19, Bruno Huber, Martin H. Zimmermann and Tom E. Mittler review recent studies of translocation of organic substances in trees. Zimmermann believes his studies substantiate the mass flow theory.

In the remaining chapters the following topics are treated: relation of bud dormancy to root growth in maple, relation of auxin to mycorrhizae, effect of light on adventitous rooting of poplar, effect of aeration on seedling root growth, cytoplasmic streaming in the cambium of white pine, tumors on white spruce, auxin in longleaf pine seedlings, photoperiodism, thermoperiodism, flowering in conifers, horticultural dwarfing, and seed dormancy in pine.

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[1] *Panchreston* is a term introduced by Dr. G. Hardin (Sci. Mo. 82: 112-120, 1956) for an "explain-all."

# *Forestry Theses Accepted by Colleges and Universities in the United States—*

## *Supplement January 1956-June 1958, Including Additions for 1900-1955*

**Compiled By**
**KATHERINE H. OSBORN**

**Subject Index By**
**RAY A. YODER**
**WILLIAM I. WEST**

In 1953, Oregon State College in Bibliographic Series No. 3,[1] published its first list of forestry theses—those for the period 1900-1952. In 1957 Bibliographic Series No. 5 was issued. This recorded forestry theses produced during 1953-1955 and earlier ones that had subsequently come to light.

The Society of American Foresters now publishes the second supplement which includes theses from January 1956 to June 1958 and additional ones from earlier years that have been discovered. It is planned that the next supplement will cover July 1958 to June 1959 as well as additional theses reported for prior years. Although old theses continue to appear it is hoped that the compilation will soon be on a current basis.

General lists of theses which include titles of interest to foresters are:

U. S. Library of Congress. Catalog Division. *A List of American doctoral dissertations printed in 1912-1938*. Washington, Gov't. Print. Off., 1913-1939.

*Doctoral dissertations accepted by American universities*, 1933/34-1954/55. New York, The H. W. Wilson company, 1934-55.

*Index to American doctoral dissertations*, 1955/56-Ann Arbor, Mich., 1957—
Issued as a 13th number of *Dissertation abstracts*.

*Dissertation abstracts; a guide to dissertations and monographs available in microfilm*. Ann Arbor, Mich., University Microfilms, 1938—

In the field of wildlife help will be found in:

*Wildlife review* (U. S. Fish and Wildlife Service) no. 59. Feb. 1950; no. 63, March 1951.
These issues list doctor's and master's theses on subjects related to the ecology and management of wildlife for 1934-1950. For later years, these are listed in the regular issues of *Wildlife Review*.

The list of forestry theses for this supplement presented alphabetically by institutions follows.

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[1]Copies may be obtained from the Director of Publications, Oregon State College, for $1.00 each.

Mrs. Osborn is a librarian at Oregon State College, Corvallis. Professors Yoder and West are with the School of Forestry at the same institution.

### *Alabama Polytechnic Institute*

**1958**

1. Kuester, Fred R. A cubic foot aerial volume table for loblolly and shortleaf pine in the upper coastal plain of western Alabama.

### *University of California*

**1955**

2. Sherburne, Friend Cook, Jr. The effects of fire on small rodent populations.

**1956**

3. Atkinson, William Allen. A method for the recreational evaluation of forest land.
4. *Burcham, Levi Turner, Historical geography of the range livestock industry of California.
5. Clemens, Roger Charles. Development of forestry courses in the secondary schools of the redwood region.
6. *Critchfield, William Burke. Morphological and physiological variation in *Pinus contorta* Dougl.
7. *Furness, David Morgan. Factors influencing the abundance of *Recurvaria milleri* Busck (Lepidoptera: Gelechiidae).
8. Gartner, F. Robert. Competition between *Lolium multiflorum* and *Ceanothus cuneatus* for nitrogen on two different soil types.
9. Graham, Charles Anson. Some reactions of annual vegetation to fire on Sierra Nevada foothill range land.
10. *Hall, Joseph G. Willow and aspen in the ecology of beaver on Sagehen Creek, California.
11. Krugman, Stanley Liebert. The anthocyanin and leuco-anthocyanins of sugar pine (*Pinus lambertiana* Dougl.) seedlings.
12. *Moore, Arthur Dudley. Studies on the toxicity of residual-type, organic insecticides to bark beetles, with special emphasis on *Ips confusus* (Lec.).
13. *Oertli, Johann Jakob. Studies on the uptake of iron by higher plants.
14. *Petit, Thomas Arthur. The economics of the softwood plywood industry.
15. *Stanley, Robert G. Respiratory patterns in germinating seeds of sugar pine (*Pinus lambertiana* Dougl.).
16. Welch, Robin Ivor. Procurement of aerial photographs for forestry purposes.
17. *Zinke, Paul Joseph. The magnitude and variation of certain soil properties associated with three forest tree species in California.

**1957**

18. *Baron, Frank Joseph. Observations of some factors associated with the germination of seeds of sugar pine (*Pinus lambertiana* Dougl.).
19. Bedell, Thomas Erwin. Rate of twig elongation and techniques of measuring browse production of *Adenostoma fasciculatum*.
20. Gorrell, Joseph Wilden. The rate of moisture loss or gain in some common forest fuels following changes in relative humidity.
21. Hoerr, Robert Charles. Consumption of paperboard in the western region of the United States, 1929-1956.
22. Merriam, Robert Arnold. Effect of fire on streamflow from small watersheds in the Sierra Nevada foothills.
23. Qashu, Hasan Khalil. Response of Jeffrey pine seedlings to some properties of serpentine soils.
24. Scharpf, Robert F. Growth and extension of the endophytic system of the dwarf mistletoe (*Arceuthobium campylopodum* Dougl.).
25. Vered, Ze'ev. Auxin in long shoots of Coulter pine (*Pinus coulteri*).

### *Colorado State University*

**1956**

26. Kirkman, Roger L. An evaluation of waterfowl production on lakes in North Park, Colorado, 1954 and 1955.
27. McCain, Edwin Adams. A problem analysis of the marketing of forest products in Colorado.
28. MacDonald, Duncan. Beaver carrying capacity of certain mountain streams in North Park, Colorado.
29. Neff, Don J. Ecological effects of habitat abandonment by beavers on a high mountain valley in Colorado.
30. Ragsdale, Dan W. Comparison of cer-

*An asterisk before a thesis indicates a doctoral dissertation.

tain methods of determining utilization of range forage.

31. Riordan, Laurence E. Selectivity and utilization of three key species of range forage by cattle, sheep, and deer in western Colorado.
32. Robinson, Harry Arthur. Migratory waterfowl crop depredation control in northern Colorado.
33. Rockett, Louis C. The experimental management of overpopulated brook trout waters.

**1957**

34. Barnhart, Roger Allen. Chemical factors affecting the survival of game fish in a western Colorado reservoir.
35. Johnson, Donald A. Waterfowl production and habitat status on the Laramie Plains, Wyoming.
36. Nichols, Lyman, Jr. Forage utilization by elk and domestic sheep in the White River National Forest.
37. Rabe, Frederick W., III. Brook trout populations in Colorado beaver ponds.
38. Rate, Henry. Effects of moisture and shade upon germination and survival of ponderosa pine in the Southwest.
39. Susong, Dunbar G., Jr. Standards for national park trail guidebooks.
40. Ward, Charles Lyman. Wildlife educational information desired by Colorado sportsmen from State game managers.

**1958**

41. Harris, John T. Analysis of elk winter range, South Fork of the White River, Colorado.

## Duke University

**1956**

42. French, Wayne E. Kiln drying green oak lumber treated with crystal urea.
43. *Griffin, Ralph H. Evaluation of certain criteria of the need for thinning even-aged loblolly pine stands.
44. Heeren, Robert D. The regeneration of loblolly pine under the shelterwood method in the Duke Forest.
45. Jiles, Robert A., Jr. Some physical and mechanical properties of particle boards.
46. *Knight, Fred B. Black Hills beetle survey methods, Rocky Mountain region.
47. Lund, Anders E., Jr. Kiln drying green scarlet oak and white oak lumber using Morton lumber cure.
48. Sechrist, Robert Arthur. The causes of latent defects in gum plywood.

**1957**

49. Barrett, James P. Determination of the organic matter content of some soils of the middle coastal plain region of Georgia and its significance in the growth of slash pine.
50. *Bilan, M. Victor. The stimulation of cone and seed production in pulpwood-size loblolly pine.
51. *Briscoe, Charles Buford. Diameter growth and effects of flooding on certain bottomland forest trees.
52. Clutter, Jerome Lee. The effect of stand conditions and angle size on plotless cruising basal area estimates in loblolly pine.
53. *Furnival, George Mason. Yield prediction of even-aged longleaf pine in the Gulf and Atlantic Coastal Plains.
54. Gleaves, William Walton. Mechanical and physical properties of gavilan (*Pentaclethra macroloba* (Willd.) Kuntze).
55. Hug, Richard Ernest. The physical and mechanical properties of certain Philippine woods.
56. Kozlik, Charles James. Mechanical and physical properties of guacimo blanco (*Goethalsia meiantha* (D. Sm.) Burret).
57. McGee, Charles E. The relation of soil properties and growth of slash pine plantations in the middle coastal plain of Georgia.

**1958**

58. *Barefoot, Aldos Cortez, Jr. Critical properties of second growth wood and abnormal wood in yellow-poplar (*Liriodendron tulipifera* L.).
59. Hitchings, Robert Grant. The pulp and paper industry in North Carolina: an economic analysis.
60. *Minor, Charles O. Yield of slash pine as derived from continuous forestry inventory data.
61. Row, Clark. The relation of soil prop-

erties and growth of slash pine plantations in the Sand Hills of South and North Carolina.

62. *Saini, Tej Bhan Singh. A study of some factors affecting costs of planting and survival of forest plantations in Virginia.

### *University of Florida*

#### *1951*

63. Gaffney, Marvin T. Financial aspects of naval stores production in northeast Florida, 1949-1950.

#### *1956*

64. Haines, Leroy W. Determination of growth rates in pine forests of Alachua County, Florida, using variables which can be measured from vertical aerial photographs.

#### *1957*

65. Hill, Harold J. The application of vertical 35 mm. aerial photography to forest management.
66. Hinkle, Edgar H. Continuous forest inventory considerations for intensively managed small Southern forests.
67. Loveless, Charles M. The mobility and composition of bobwhite quail populations in south Florida.
68. Mocha, John E. Contributions to the development of a laboratory method for evaluating wood preservatives against termite attack.

### *University of Georgia*

#### *1932*

69. Bishop, George Norman. A study of the relation of season to resin concentration in loblolly pines.

#### *1933*

70. May, Jack Truett. Effect of density of stocking on the growth and development of longleaf, loblolly, and slash pine seedlings.

#### *1950*

71. Cannon, Robert Walter. A comparison of the trends in prices of lumber, logs, and stumpage with the general price level of all commodities.
72. Davenport, Edward Alton. A financial aspect of planting versus natural reproduction of loblolly pine in the Georgia Piedmont.
73. Edney, Robert Emerson. Some preliminary steps in the management and utilization of *Paulownia tomentosa*.
74. Greene, Monroe Ford. Type mapping and random cruising using aerial photographs.
75. Greer, Edgar S. An examination of some aspects of forest geography in Georgia.
76. Parnell, Cheves W. A study of the concentration of sawtimber and cordwood stands in Georgia.
77. Smith, James LeRoy. A study of forest acreages in Georgia.
78. Todd, Donnie Percy. The relative accuracy of a 5, 10, and 20 per cent cruise on 50 and 100 acres in the Watson Springs Forest.

#### *1951*

79. Hamilton, Marshall Edward. Random versus average diameter breast high measurements of pine trees in the Piedmont.
80. Knight, Vernon James. Forestry agencies in Georgia, 1900-1951.
81. Moore, J. W. The relative time required for a 5, 10, 20, and 40 per cent cruise using 1/4 and 1/5 acre circular plots.
82. Tinker, Frank E. The relative accuracy of 1/10, 1/5, 1/4, and 1/2 acre plots on a 10 per cent cruise of 50 and 100 acres.

#### *1952*

83. Baxter, Harold Owens. Tree basal area growth as compound interest rates.
84. Miller, Morris L. Distribution by compass direction of the long and short diameters and radii of shortleaf pine stumps.

#### *1953*

85. Riley, Owen Lowry. Age class-area study for a portion of the George Walton Experimental Forest.

#### *1954*

86. Johstono, Hugh Emmett. A study concerning the diameter increment of

residual pine saplings in the southern Piedmont.

87. Reeves, Julian Dow. A study of information and education activities related to forest fire occurrence in several Georgia counties.
88. Starr, John Walter. The relative accuracy of three patterns of sampling point spacings in using Batterlich's method for determining basal area on 50 and 100 acres.
89. Webb, Charles Herschel. Biological characteristics of the white-tailed deer herd and an evaluation of the range in the Blue Ridge game management area.

**1955**

90. Kreis, Edgar Antone. The relationship of growth, age, and spacing in slash pine (*Pinus elliotti*) plantations for various site indices.
91. Ross, Roy Delbert. A preliminary study of cove forests in the Georgia Piedmont.
92. Teate, James Lamar. A study of the influence of informational and educational activities on forest fire occurrence.
93. Walker, George Dean. A study of bottomland hardwood types in the Georgia Piedmont.

**1956**

94. Jones, LeRoy. A watershed study in putting a hardwood forest at the Coweeta Hydrologic Laboratory in the southern Appalachian Mountains under intensive management.
95. Perry, Joe Drayton. An economic study of the planing mills in a selected area, and their relation to the lumber industry.

**1957**

96. Dumbroff, Erwin Bernard. Initial field survival and height growth of Arizona cypress (*Cupressus arizonica*) in south Georgia.
97. Hogan, Leonard David. The relationship between years to heal and certain measurable variables in pruned slash pine *(Pinus elliottii)*.
98. McAlpine, Robert Gooding. Age of tree and root development by air layers in loblolly pine.
99. Peterson, David Wallace. A study of the population dynamics of the Eastern mourning dove (*Zenaidura macroura carolinensis*) in Oconee County, Georgia.
100. Shain, William Arthur. Plantation management of Arizona cypress (*Cupressus arizonica*) for Christmas trees in Georgia.

**1958**

101. Jones, Earle P. The effect of five variables on the form class of plantation grown slash pine (*Pinus elliottii* Engelm. var. *elliottii*).
102. Thomas, William P. A comparison of the biological characteristics of two north Georgia deer herds in relation to range condition.

### Harvard University

**1956**

103. Murison, William F. *Fomes annosus* (Fr.) Cke. on certain red pine (*P. resinosa* Ait.) plantations in the Harvard Forest.
104. *Stephens, Earl P. The historical-developmental method of determining forest trends.

**1957**

105. Patric, James Holton. The relationship of species distribution to moisture in Compartment I, Tom Swamp Block, Harvard Forest.
106. *Snider, Philip Joseph, Jr. Rhizomorph development in *Armillaria mellea* (Vahl ex Fr.) Quel.
107. Wilson, Brayton Fuller, Jr. A study of shake in eastern hemlock.

**1958**

108. *Brown, Claud Lafayette. Studies of growth and development in longleaf pine seedlings.
109. *de Percin, Fernand Pétrégille, Jr. Microclimatology of a subarctic spruce forest and a clearing at Big Delta, Alaska.
110. *Ross, Philip. Microclimatic and vegetational studies in a cold-wet deciduous

forest.

111. *Zaremba, Joseph. Some problems in forecasting future wood requirements.

### University of Idaho

#### 1956

112. Bynum, Hubert Hartford, Jr. Artificial inoculation of pole-sized western white pine with *Armillaria mellea* (Vahl ex Fries) Quel.
113. Chupp, Norman Richard. An evaluation of the lower Coeur d'Alene River waterfowl habitat in Kootenai County, Idaho.
114. Gansel, Charles Ray. A comparison of some morphological features of needles from blister rust-resistant and non-resistant western white pine.
115. Harshman, Edmund Paul. The changes in vegetation following biological control of *Hypericum perforatum*.
116. Heebner, Gordon C. A study of the life history and ecology of the blue grouse in west central Idaho.
117. McAlister, Robert Tardy. The variation of specific gravity in Douglas fir of the Inland Empire type.
118. McClure, Norman Robert. Grass and legume seedings on burned-over forest land in northern Idaho and adjacent Washington.
119. Roberts, Hadley Burnett. Food habits and productivity of white-tailed deer in the Hatter Creek enclosure.

#### 1957

120. Beeman, Robert David. Salt in the management of elk and other wildlife in the lower Selway River area.
121. Bjornn, Theodore C. A survey of the fishery resources of Priest and Upper Priest Lakes and their tributaries, Idaho.
122. McConnell, Burt. Productivity of mule deer on the Cassia division of the Sawtooth National Forest.
123. Oien, Waine E. A pre-logging inventory of four trout streams in northern Idaho.

#### 1958

124. Bachmann, Roger W. The ecology of four north Idaho trout streams with reference to the influence of forest road construction.
125. Brown, E. R. The use of sodium TCA and Dalapon to control the competition of perennial grasses with bitterbrush seedlings.
126. Nichle, W. R. Nematodes associated with the rootlets of western white pine in northern Idaho.

### Iowa State College

#### 1956

127. Clark, Wendell Phillips. Effect of tension wood on the seasoning and machining of eastern cottonwood.
128. Crowther, Charles Richard. Weed control methods related to establishment and growth of young planted conifers.
129. Haskell, Henry Hamilton. Gluing properties of tension wood in eastern cottonwood using cross-lap and block shear test specimens.
130. Herrick, David Edwin. Tractive force required to skid hardwood logs.
131. *Thomson, George W. Growth of plantation black walnut in southeastern Iowa as related to certain soil properties.
132. Wahlgren, Harold Emil. Effect of tension wood on the longitudinal shrinkage and specific gravity of eastern cottonwood.

#### 1957

133. *Brendemuehl, Raymond Hugo. Growth, yield, and site requirements of eastern cottonwood.
134. Van Deusen, James Lowell. Effect of controlling competition on the establishment of young conifers in plantations.

#### 1958

135. Burton, James Donald. Influence of moisture-conserving treatments on survival of pines planted on coal spoils.
136. Lassen, Laurence Eivind. Effect of tension wood on density, toughness, and endwise compression of cottonwood.
137. Renaud, Ray Eldon. Evaluation of glue line quality by block shear, plywood shear, and cross-lap test specimens.
138. Robinson, Vernon Lee. Economic feasibility of red oak lumber concentration yards in northeast Iowa.

139. Wilhite, Lawrence Paul. Drought injury and death of red pine (*Pinus resinosa* Ait.) in relation to site.

### *Louisiana State University*

**1926**

140. Stahl, Henry Justin. Reforestation and lumbering in Louisiana.

**1927**

141. Wheelis, Willis Bryan. The forest trees of Louisiana and insects attacking them.

**1928**

142. Voorhies, Louis Joseph. Use of creosoted lumber for construction of storm sewers.

**1929**

143. Cranfill, Gordon R. and J. R. Heard. Investigation of liquid rosin from southern yellow pine.
144. Elliott, D. Clements. The biology of the cottonwood leaf beetle and its North American distribution.
145. Walker, Talmadge P. The severance tax of Louisiana.

**1934**

146. Hunter, Alice Pleasance. Animal succession in a southern Louisiana pine community.

**1936**

147. Allen, Rea. The newsprint paper industry for the South.
148. King, Helene. The economic history of the Long-Bell Lumber Company.
149. Norgress, Rachel Edna. The history of the cypress lumber industry in Louisiana.
150. Roberts, Edward Guernsey. The effect of annual burning of longleaf pine stands on bacterial numbers in the soil.

**1937**

151. Hanson, Walter O. The rate of absorption of different liquids by the wood of various southern tree species.
152. Russell, Ernest James. The possibility of fire insurance for the timberlands of the South.

**1939**

153. Drummond, Don Maphet. Elements of forest recreation.

**1940**

154. Wixson, Joseph Arthur. The cause classification of forest fires in the South.

**1942**

155. Quick, Amy. The history of Bogalusa; the "magic city" of Louisiana.

**1949**

156. Bell, Marvin Thomas. The wild turkey in southeast Louisiana.

**1950**

157. Phares, John Haden. A study of beaver in Amite County, Mississippi.
158. Thigpen, Thomas Doyle. A study of beaver in Louisiana.

**1951**

159. Crowther, Charles Edward. An evaluation of game range on three loess hills farms in Yazoo County, Mississippi.

**1956**

160. Adams, Raymond Jean. Relationship of Girard form class to lower bole taper.
161. Schores, David Damotte. The effect of certain stand conditions on the radial growth of dominant loblolly pine in southeast Louisiana.

**1957**

162. Brunett, Louis Elwood. Squirrel populations in relation to forest types in Zemurray's Park, Tangipahoa Parish, Louisiana.
163. Chabreck, Robert Henry. A study of beaver in St. Tammany Parish, Louisiana.
164. Hansbrough, Thomas. Soil fumigation for the control of nematodes and the effect of nematodes on the survival, growth, and development of loblolly pine seedlings.
165. Lambert, Dinnie Franklin. The effect of competition on diameter growth of water oak.
166. McLemore, Bobbie Frank. Effect of geographic origin of seed on the dry-

matter content of loblolly pine needles.

167. Moore, James Emmett. Factors affecting the natural pruning of spruce pine.

168. Sheffield, William James, Jr. A summer deer food study in Tensas Parish, Louisiana.

169. Williams, Clifford Terry. Seed production of common lespedeza interplanted with second-growth longleaf pines in Tangipahoa Parish, Louisiana.

**1958**

170. Anderson, Kermit Austin. The origin and growth of bottomland reproduction.

171. Burchfield, Oliver Keith. Variation in precision with merchantability classes in prism estimates of basal area.

172. Gaddis, Billy Tillson. Forestry practices under the agricultural conservation program in Mississippi.

173. Kitt, Paul Duane. Ownership factors affecting the management of small forest tracts in St. Helena Parish, Louisiana.

174. Merrifield, Robert Glenn. Annual growth of loblolly pine as related to seasonal soil moisture deficiencies.

175. Toney, Jerry Luther. Equilibrium moisture control in building structural members.

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**1956**

176. Drisko, William Henry. A study of the effects of the application of marking rules upon stand conditions in a spruce-fir forest in eastern Maine.

**1958**

177. Sewell, Joseph Herbert. A comparative study of the development of forest policy in Maine and New Brunswick.

### *University of Massachusetts*

**1956**

178. Boyle, John D. An evaluation of stocking New Brunswick hare (*Lepus americanus*) in Massachusetts mixed forest habitat.

**1958**

179. Dodge, Wendell E. Investigations concerning the repellency and toxicity of various compounds for control of porcupine (*Erethizon dorsatum dorsatum*).

180. Kupa, John Joseph. Massachusetts ruffed grouse studies, 1956-1958.

181. Werner, Jack W. Massachusetts ruffed grouse studies, 1954-1956.

### *Michigan State University*

**1956**

182. *Freeland, Forrest D., Jr. The effects of a complete cutting of forest vegetation and subsequent annual cutting of regrowth upon some pedologic and hydrologic characteristics of a watershed in the southern Appalachians.

183. *Hodgkins, Earl J. Some early effects of prescribed burning on the soil, forest floor, and vegetation in the loblolly-shortleaf pine forest of the upper coastal plain of Alabama.

184. *Palley, Marshall N. A proposed technique for measuring and comparing the economic importance of timber and wildland recreation in Michigan.

185. Smalley, Glendon W. Some criteria for determining unit area control in watershed management on municipal and industrial watersheds in the southern Appalachians.

186. Verme, Louis Joseph. Production and utilization of acorns in Clinton County, Michigan.

187. *Yoho, James G. Private forest land ownership and management in thirty-one counties of the Lower Peninsula of Michigan.

**1957**

188. Barker, Alfred A. Delamination in screw cap closures.

189. *Blankenship, Lytle H. Investigation of the American woodcock in Michigan.

190. *Cool, Bingham Mercur. An investigation of the effect of some production techniques and weather factors on maple sap and sugar yields in a central Michigan woodlot.

191. *Goff, James W. The damping capacity of corrugated paperboard as a function of stress and frequency.

192. *Hudson, Robert Keith. The influence

of microclimate on the establishment and early survival of planted red pine (*Pinus resinosa* Ait.) in southwestern Michigan.

193. Lancaster, Roland K. Strength variations of bilaterally oriented rubber hydrochloride film.

194. *May, Jack T. Effects of soil management practices in a forest tree nursery on soil properties and on loblolly pine seedlings.

195. Schofield, Raymond Dale. A study of rabbit survival on a public hunting area.

196. Siegel, William Carl. An investigation into the effect of season upon the effectiveness of four methods of hardwood control for red pine plantations in lower Michigan.

**1958**

197. Gammon, Alvin D. Natural regeneration on a forty-five acre oak-mixed hardwood area seven years after clear cutting.

198. Haygreen, John G. Determining the dry weight and dry volume of green aspen bolts by use of the water displacement technique.

199. *Huey, Ben M. Selected economic alternatives for logging lodgepole pine.

200. Kearns, Frank. Effects of gibberellic acid on young forest trees.

201. Larmore, Frederick D. The influence of specific gravity and resin content on the properties of particle board made with species of widely different specific gravity.

202. Niloofari, Parviz. Macroscopic identification of most important Iranian woody species.

203. Quinkert, Anthony K. Survival and growth of mixed hardwood plantations in southwestern Michigan.

204. Schulz, Gerald L. The stiffness of scores of folding boxboard as a function of scoring rule, make ready, penetration, and moisture.

205. *Sullivan, John D. An analysis of shear failure of wood subjected to fatigue loading.

## *University of Michigan*

**1953**

206. *Webb, Frank Ernest. An ecological study of the larch casebearer (*Coleophora laricella* Hbn.) (Lepidoptera: Coleophoridae).

**1954**

207. *Adams, Arthur Kinney. Some physicochemical effects of beaver dams upon Michigan trout streams in the Watersmeet area.

208. *Gilligan, James P. The development of policy and administration of Forest Service primitive and wilderness areas in the Western United States.

209. *Lachance, Paul Emile. A study of the pulp and paper industry of the Province of Quebec in relation to its present and future wood supplies.

210. *Lamb, Frank Bruce. Utilization, distribution, and management of tropical American mahogany.

211. *Sylvester, Walter Robert. "Grass-roots" conservation: a study of conservation programs affecting private land-use practices in middle Michigan.

212. *Wallace, Oliver Pagan. Methods for obtaining minimum cost logging in northern New York and New England.

**1955**

213. Drury, Herbert Rentschler. Natural history, conservation, and ecology of the musk ox.

214. Hooke, Richard Harris. Some observations on the Finnish forest industry.

215. *Wilcox, Arthur Thomas. Selected factors affecting the summer use of public campgrounds in five counties of northern Michigan.

**1956**

216. Barclay, Woodrow Herman. Relation of site factors to stand density of Scotch pine after attack by pine spittle bug and tip blight in Stinchfield woods.

217. Benzie, John Willard. Federal income taxation of forest properties.

218. Brady, James John. An analysis of the Echo Park dam controversy.

219. Brock, Samuel Mitchell. Estimation of stand volume and basal area growth for red pine.
220. Brunette, Andre Paul. Site analysis through use of environment factors: a method of determining proper species for an open field site.
221. Clausen, Bernard Ladu. The effects of a commercial fertilizer on growth and consumption of forage in a marsh grass pasture.
222. Cooley, John Hale. Computation of annual growth in white pine using stem analysis.
223. *Craine, Lyle Eggleston. The Muskingum watershed conservancy district: an appraisal of a watershed management agency.
224. Criley, Walter Lockwood. Reservoir shoreline development in the Tennessee Valley: a study in land-water relations and the planning process.
225. Foster, Charles H. W. Wildlife use of utility rights-of-way in Michigan.
226. *Franz, Norman Charles. An analysis of the wood-cutting process.
227. Hart, George Emerson. Levels of growing stock in a white pine plantation from establishment to major harvest.
228. Huddle, Howard Lewis. Winterkill of fish in lakes and its relation to physical and chemical factors of the environment.
229. Kadlec, John Adolph. The effects of water level management on two central Wisconsin marshes, 1950-1954.
230. Kraus, John Franklyn. Relationship of soil moisture to the transition from springwood to summerwood of red pine in southern Michigan.
231. Makela, Howard Jacob. A study of land use integration in the Waterloo Recreation Area and recommendations for intensive management.
232. Mason, Richard Randolph. Weather and other influences affecting poplar borer (*Saperda calcarata* Say) populations in northern Michigan.
233. Miller, Sharon Raymond. The growth of hardwoods on sandy soils in lower Michigan.
234. *Quick, Horace Floyd. The fur resources of a wilderness region in northern British Columbia.
235. Sucoff, Edward Ira. Four factors influencing summerwood production in red pine.
236. Wagar, John Alan. An analysis of the growing stock and structure of a tract of unevenaged hardwoods in southern Michigan.
237. Webster, Henry Hickler. An economic analysis of mine timber marketing in West Virginia.
238. Whitmore, Frank William. Early development in eastern white pine of various seed sources grown in central New England.

**1957**

239. Bengelsdorf, Marvin Frederick. Expressing gap-filling properties of a wood adhesive as a numerical value.
240. Bulgrin, Erwin Herman. A survey of pulpwood loading and hauling with self-loading trucks equipped with the Hiabob hydraulic pulpwood loader.
241. Crawford, Hewlette Spencer. A study of some factors in the fawning complex of the white-tailed deer.
242. Hann, Robert Allen. A method of quantitative topographic analysis of wood surfaces.
243. Heikkenen, Herman John. Balsam fir ecology: an analysis of the literature.
244. *Hibbs, Clyde William. An analysis of the development and use of outdoor laboratories in teaching conservation in public schools.
245. *Hunt, George Sylvester. Causes of mortality among ducks wintering on the lower Detroit River.
246. Hunter, William Frederick. A study of conservation education in the Cedar Lake and Mill Lake Group camps.
247. Irwin, John David. Shrinkage failure of wood as influenced by temperature and moisture content.
248. *Latta, William Carl. The ecology of the smallmouth bass (*Micropterus d. dolomieu* Lacépède) at Waugoshance Point, Lake Michigan.
249. Lohrey, Richard Erwin. Growth and development of a mixed conifer plantation in upper Michigan.

250. MacDonald, Duncan Ross. Effects of aerial spraying on two overwintering parasites of the spruce budworm.

251. McMahon, Robert E. Resource education and the school forest in the public schools, Merrill, Wisconsin.

252. McMillin, Charles Wescott. The relation of mechanical properties of wood and nosebar opening in the production of veneer.

253. Maroney, William Halsey. The effect of testing speed on certain wood adhesives as measured by the cross-lap specimen.

254. Miller, Orson Knapp. An analysis of the productive potentialities of two southern Michigan oak-hickory stands.

255. Mosher, Harry Lloyd. The farm woodlot management problem and a case study of an oak-hickory forest.

256. Nelson, Ted William. A consulting forestry firm for California's second-growth pine region—an analysis of the possibilities.

257. Olsen, Peter Fredrick. Some aspects of the ecology of the muskrat (*Ondatra zibethicus* (Linn.) ) at Delta, Manitoba.

258. Schneider, Gerhardt. A comparison of various growth prediction methods on Ringwood Forest.

259. *Sippell, William Lloyd. A study of the forest tent caterpillar (*Malacosoma disstria* Hbn.) and its parasite complex in Ontario.

260. *Smith, Arthur Dwight. The status of federal land grant lands in Utah and proposals for their management.

261. Smithberger. Thomas John. A comparison of short-term growth prediction methods as applied to a pole-size ponderosa pine plantation in southeastern Michigan.

262. Striffler, William David. The soil moisture regime under native hardwoods at five elevations in the southern Appalachians.

263. Williams, Carroll Burns. Spring emergence of the European pine shoot moth (*Rhyacionia buoliana* (Schiffermuller) ) in Stinchfield Woods.

**1958**

264. Black, Peter Elliott. Interception in a hardwood stand: the loss of rainfall due to a covehardwood forest type in the southern Appalachian Mountains.

265. Bruneau, Glenn Philip. Some factors influencing cupping in lumber core plywood.

266. Clements, John Richard. The influence of fire on the development of the pine forest in part of Section 30, T46N, R36W, Iron County, Michigan.

267. Collins, Robin Algwynne. Old-growth red pine in lower Michigan.

268. Farmer, Robert E. Some effects of prescribed burning following clear-cutting in poor site aspen.

269. Felland, Jeremy Reid. The conservation reserve: a program for better land use.

270. Johnson, Walter. Preliminary study of a bolter saw operation in southeastern Michigan.

271. Kamrath, Richard Herbert. Wood-moisture relationships of yellow birch laminates impregnated with phenol-formaldehyde resin.

272. Lord, William Boyne. The Wisconsin domestic charcoal market: a case study in forest products marketing research.

273. McArdle, John Parker. The release of pine in lower Michigan.

274. Meagher, Margaret Mary. A comparative deer browse and herd density study 1949—1958, on the George Reserve.

275. Menzel, Karl Edwin. Seasonal and annual changes in weights of George Reserve deer.

276. Paton, Roger George. Flood adjustments in the Naugatuck Valley since 1955.

277. Radtke, Robert Earl. Some engineering techniques used in wildlife management.

278. Scheffey, Alice W. The origin of recreation policy in the national forests: a case study of the Superior National Forest.

279. Sherman, Alonzo Joseph. The organization and operation of the Kiyosato Educational Experiment Project's farm, Kiyosato, Japan.

280. Trefts, Hubbard. Red pine and the white-pine weevil.

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**1955**

281. Froelich, Ronald. The effect of April to July rainfall on the basal area growth of *Populus tremuloides* in years preceding and in years of forest tent caterpillar defoliation.

282. Hamilton, John. Swamp vegetation control by chemical spray.

283. Jones, John R. (a) A cost comparison of three logging methods in northern Minnesota. (b) Geographical gradation of species composition in the Lake States northern hardwood types, with suggestions as to their climax status.

284. Lundgren, Allen L. The acquisition and disposition of the United States public domain.

285. Shiue, Cherng-jiann. (a) Effectiveness of disking to secure natural reproduction of northern hardwoods on poorly stocked and sodded sites. (b) Natural reproduction of old-growth northern hardwoods after different methods of cutting.

**1956**

286. Howard, John. Trends in American sawmilling.

287. *Kemp, Arne K. Study of factors associated with the development of collapse during kiln drying of aspen lumber.

288. Meyer, Daniel. (a) The effect of defoliation by the forest tent caterpillar (*Malacosoma disstria* Hbn.) on the mortality, twig mortality, and leaf size of aspen in northern Minnesota. (b) The relation of soil horizon texture and acidity to the site index of aspen in northern Minnesota.

289. *Meyer, Merle P. Some observed effects of variations in photographic papers upon image perception in stereo vertical aerial photographs.

290. *Willingham, James W. The estimation of forest management inventory data from aerial photographic measurements.

**1957**

291. Conover, David T. Needle length of jack pine as affected by seed source and other factors.

292. Opsal, Philip M. A study of the natural durability of diamond willow heartwood.

293. Presteman, Dean. A study of the relationship between the weight/volume ratio and moisture content of wood in a limited sample of jack pine and quaking aspen.

294. Purcell, Robert C. (a) Building permit analysis city of St. Paul 1955-1956. (b) Monkeypod wood and its significance in the manufacture of hardwood specialty products in Hawaii and the United States. (c) A lumber grade-yield analysis of circular headsawing and sash gangsawing aspen logs.

295. Rudolph, Thomas. (a) Comparison of three methods of sampling moisture content in pulpwood. (b) Preliminary Minnesota forest genetic survey with emphasis on jack pine.

296. Salzman, James A. A resurvey of a black spruce reproduction study 10 years after cutting.

297. Scott, Donald H. The effect of temperature and precipitation upon the radial growth of red pine in northern Minnesota.

298. *Wallin, Walter B. The influence and importance of defects and log grades on lumber grade yield from aspen logs.

**1958**

299. *Avery, Thomas E. Construction and test of a composite aerial volume table for southern pines and hardwoods.

### *University of Missouri*

**1956**

300. Neebe, David Joel. The silviculture of eastern cottonwood with special reference to thinning.

301. Puchbauer, Truman C. A management

plan for the timber resources of the Mingo Natural Wildlife Refuge.

**1958**

302. Whipkey, Ronald Z. Some basic hydrologic relationships for three small watersheds in the Missouri Ozarks.

### *Montana State University*

**1952**

303. Post, Warren Arthur. The nation's recreation or power production and flood control: a study in land use.

**1953**

304. Cech, Franklin Charles. 2, 3, 5-triphenyl tetrazolium chloride as a viability indicator of seeds of certain broadleaf species.
305. Fredeking, William J. The development of reproduction following a seed tree cutting of a larch stand in northwestern Montana.
306. Spencer, John Small, Jr. A study of the ponderosa pine risk rating system.

**1954**

307. Geis, Anthony F. The food consumption and relative digestibility of various winter diets fed to elk (*Cervus canadensis nelsoni*).

**1955**

308. Morrison, Lloyd Wesley. The poster in forest fire prevention.
309. Nelson, Howard S. The phenology of goatweed (*Hypericum perforatum*) in relation to the behavior of goatweed beetles (*Chrysolina gemellata* and *C. hyperici*) in western Montana.
310. von Diechmann, Vollrat. The American forest fire danger meter.

**1957**

311. Covey, William H. A time study and cost analysis of shearing wild stands of Douglas fir Christmas trees.
312. Dyson, Peter John. A study of the ponderosa pine risk rating system in Montana.
313. Gerlach, Frederick L. Low altitude stereo-photo timber sampling by helicopter.
314. Helwig, Lawrence Leonard. The value of conifers as a winter feed for elk (*Cervus canadensis nelsoni*) determined under controlled conditions.

**1958**

315. Boll, Louis Arthur. Elk nutrition—the response of elk calves to various winter diets under controlled conditions.
316. Yao, Joe. An investigation of some physical and mechanical propertes of reconstituted wood particle boards of sandwich type when using different types of resin in core and faces.

### *University of Nebraska*

**1907**

317. Pearson, Gustaf Adolph. The light requirements and leaf structure of tree seedlings.

**1910**

318. Coons, George Herbert. Investigations of *Gymnosporangium juniperivirginiamae* Schw.

**1911**

319. Pipal, Francis John. The annual increment in a tree.

**1912**

320. Sponsler, Olenus Lee. A study of the bark of some of our forest trees.

**1915**

321. Nelson, Enoch Wesley. Studies in the drought-resistance of certain species of *Pinus*.

**1918**

322. Mogensen, Annie Martha. The relative transpiration of broad-leaved trees and conifers in summer and winter.

**1923**

323. Armstrong, Ellen. A study of water conduction in woody plants.

**1927**

324. *Aikman, John Mulvaney. Distribution and structure of the forests of eastern Nebraska.

**1928**

325. Starr, George Herman. The effect of various stimuli upon the callusing and rooting of hardwood cuttings.

**1930**

326. *Holch, Arthur Everett. Development of roots and shoots of certain tree seedlings in different forest sites.

**1931**

327. Kiener, Walter E. On the vegetation of an isolated peak in the Rocky Mountains.

328. Sperry, Omer E. The rate of growth of the western yellow pine in Estes Park.

**1934**

329. *Sperry, Omer E. The rates of growth of the conifers of the Rocky Mountain National Park.

**1935**

330. *Biswell, Harold H. Effects of environment upon the root habits of certain deciduous forest trees.

**1939**

331. *Kiener, Walter. Sociological studies of the alpine vegetation on Longs Peak.

**1941**

332. *Wright, Ernest. Damping-off of deciduous seedlings and its control in nurseries of the Great Plains region.

**1951**

333. *Shepherd, Weldon Owen. Ecological responses to grazing, burning, and logging in pond pine forests.

### *University of New Hampshire*

**1956**

334. Rawlings, William Rippey. Plant succession following logging in white pine stands and its relationship to wildlife abundance.

**1958**

335. Woodward, Edwin Charles. Observations on greenhouse management of white pine seedling nutrition.

### *State University of New York College of Forestry, Syracuse*

**1956**

336. Abelson, Joseph. Neutral sulfite semichemical and sulfate pulping of American beech.

337. Andersson, Birger. Investigations of factors influencing the strength properties of paper treated with thermoplastic resins.

338. Andersson, Rune. The effect of temperature on the electrical resistance of wood.

339. *Bhargava, Roshan Lal. Studies of paper plastic combinations.

340. Cowling, Ellis Bervier. Preservative tolerances in a group of wood destroying fungi.

341. Crossley, Robert D. The effects of five sapstain fungi on the toughness of eastern white pine.

342. Dalheim, Stuart A. The curing of paper-resin combinations with radiant heat.

343. Davidson, Robert Wheeler. Stress-strain relationships in the toughness test for wood.

344. Decker, Harry V., Jr. An evaluation of the tree planting program of the New York State Forest Practice Act in Onondaga County.

345. Duncan, Thomas Francis. A study of the franchised dealer system as used by one manufacturer in distributing prefabricated houses.

346. Heilman, William J. Methyl affinities of substituted aromatic compounds.

347. Hewlett, John D. The development of vegetation on the Solvay waste beds.

348. Hori, Hiroshi. Printability of coated paper.

349. Hovey, Stanford T. Convergent photography versus vertical photography: a study of relative vertical accuracy obtained with the Balplex stereoplotter.

350. Johnson, William Patrick. An investigation of the gluability of a hardboard panel to a wood frame using radio frequency stray field heating.

351. Kim, Chul Yong. Federal flood control laws and administration in the United States since 1935.

352. King, Meng-Wu. Semichemical pulping of white birch wood with ammonium bisulphite solutions.

353. Leak, William Bard. The values of cultural subjects to the professional forester.

354. *Leavitt, Frederick C. Methyl affinities of various olefinic and aromatic com-

pounds.

355. *Lenz, Robert William. Approaches to the problem of the location of xanthate groups in glucose and cellulose xanthates.

356. McKenzie, Thomas Allan. Input-output classification of forest production.

357. Marder, Herman Lowell. Phenol-formaldehyde wet strength resins.

358. *Martinelli, Mario, Jr. Some hydrologic aspects of alpine snowfields under summer conditions.

359. Meyering, John R. Woodworking safety—needs, values, recommended program for medium-sized plants.

360. Noldan, Henry Curt. A study of the current work load performed by the district ranger in accordance with job load analysis and program and work planning procedures of the United States Forest Service.

361. *Pentoney, Richard Ellis. On the low-stress rheologic behavior of wood.

362. *Sarkanen, Kyösti. Studies on the ethanolysis reaction of spruce lignin.

363. Shottafer, James Edward. The suitability of cativo and guanacaste for lumber core stock.

364. *Silver, George Thomas. Studies on the arborvitae leaf-miners in New Brunswick.

365. *Throssell, John Julian. Carbon-bromine bond dissociation energies and the stability of certain hydrocarbon radicals.

366. Van Nierop, Emmanuel T. G. An evaluation of several organic mulches on a sandy loam forest.

367. Villarreal, Ramiro. Neutral sulfite semi-chemical pulping of Kochle (*Cecropia obtusifolia*).

368. Weinberg, Ernest E. A. A study of farm woodlot owners who are co-operators and non-cooperators under the New York State Forest Practice Act.

369. Wheeler, Edwin Y. Design improvement in small diameter spring set circular saws.

370. Wood, Robert S. The influence of deep-lying fine layers on significant growth variations of a red pine (*Pinus resinosa* Ait.) plantation.

371. *Zerbe, John I. Sources of variability encountered in determining the impact strength of wood and the effect of incremental loading on absorbed energy and elastic properties.

**1957**

372. *Arlt, Herbert George, Jr. Lignin structural studies: Part I. Studies of branching of lignin. Part II. Investigation of lignin degradation products prepared by hydrogenation.

373. *Baker, Robert D. The determination of commercial sawtimber - s t u m p a g e values: a critical analysis of the U. S. Forest Service basic stumpage appraisal system.

374. Barber, Richard Paul. The internal treatment of paper with polyvinyl acetate.

375. Battarbee, George E. Intensive forest management: a review of current principles and procedures.

376. Beecher, H. Gere. A study of contractor acceptance of prefabrication by selected areas within New York State.

377. *Beredjick, Nissim. Investigation on asymmetric synthesis of copolymer and polymer systems.

378. Bernhardt, Robert W. Growth of fish in the waters of the Huntington Wildlife Forest.

379. Brumbaugh, James Irvin. The effect of specific gravity of four species on the bending strength and water absorption of flakeboard.

380. *Christensen, Wallace W. A methodology for investigating forest owners' management objectives.

381. Francia, Faustino C. The ambrosia and the powder-post beetles in the Philippines.

382. *Horn, Allen Frederick, Jr. Resource policy and forest industry development in Pennsylvania.

383. *Hosner, John F. Regeneration and succession in bottomland hardwoods in southern Illinois.

384. James, Robert Evan, Jr. A preliminary experiment with high pressure preservative treatments.

385. *Johnson, Evert W. Evaluation of site

index for longleaf pine using aerial photographic evidence.

386. Juillet, Jacques A. The European pine shoot moth and its parasites in Europe with observations on European parasites in America.

387. Kuhn, John Henry G. Corrosion inhibitors in paper packaging.

388. *Lussier, Louis-Jean. Establishment and use of production standards in forest exploitation.

389. Milkovich, Ralph. Polymerization initiated by electron transfer to monomer.

390. Miner, Norman Hartley. Watershed hydrology applied to two Adirondack streams.

391. Mitchell, Russel Gene. The balsam woolly aphid in the Pacific Northwest.

392. Nagel, William Payne. Effects of temperature and humidity on the development of the locust seed weevil (*Amblycerus robiniae* (Fab.) ).

393. *Nelson, Russell. Factors influencing the removal of pentosans from wood by alpali: evidence on the lignin-carbohydrate bond.

394. Nichols, James Otis. Some effects of the balsam woolly aphid (*Adelges piceae* (Ratz.)) on Pacific silver fir (*Abies amabilis* (Dougl.) Forbes).

395. O'Keefe, Timothy Gerard. History and management potential of a farm woodlot in Onondaga County, New York.

396. Riedell, Andrew Weste, Jr. A study of factors influencing solvent release from wood fillers.

397. *Rogers, Charles Edwin. The permeation, diffusion, and solution of organic vapors in polyethylene.

398. Ryan, Paul Wynne. A method for determination of deer movement patterns.

399 *Schonfeld, Edward. The kinetics of cationic polymerization initiated by proton transfer.

400. Smid, Johannes. Reactions of ethyl and N-propyl radicals in solution: Part I. The kinetics of decomposition of propionyl and butyryl peroxide in solution. Part II. Addition of ethyl and N-propyl radicals to aromatic compounds.

401. Smith, James Wesley. A critical analysis of some methods of establishing ground control for aerial photography.

402. *Steinhoff, Harold W. The dusky grouse and its ecology in Colorado.

403. Wang, Chung K'uei. Zonation of vegetation on Taiwan.

**1958**

404. Alex, Nicholas Harry. The evaluation of gas transmission rates of flexible packaging materials.

405. Anderson, Alexander Murray. A problem analysis of a white pine stand in south-central Nova Scotia.

406. Bailey, James Allen. The utilization of closed conifer plantations by wildlife.

407. Booker, Evans. Extraction of hemicelluloses from woody tissues.

408. *Brandt, Robert William. Needle cast disease of Douglas fir in New York Christmas tree plantations.

409. *Buckley, Ronald P. Methyl affinities of olefinic compounds.

410. Burger, John H. Testing the durability of exterior natural finishes.

411. Clark, Philip C. The effect of fiber length on the physical properties of paper.

412. *Côté, Wilfred A., Jr. An electron microscope investigation of the organization and fine structure of the secondary cell walls of wood.

413. Daughtrey, Thomas K. The effects of drying temperatures and methods of drying yellow birch veneer on glue bond quality and hygroscopicity.

414. Hampson, Robert John. An approach to improved use of private woodlots through industrial cooperation.

415. Hick, Robert Milton, Jr. Measurement of the telegraphing defect in particle board overlays and analysis of several production techniques.

416. *Juillet, Jacques A. Studies of introduced parasites of the European pine shoot moth (*Rhyacionia buoliana* (Schiff.)).

417. Jurecic, Anton. Studies on wet strength of paper.

418. *Kohlbrenner, Philip John. The alcohol-benzene soluble extractives of Sitka

spruce (*Picea sitchensis* Carr).

419. *Ladacki, Michael. Anionic polymerization and block polymerization of certain vinyls and butadiene.

420. Lanner, Ronald Martin. American trees in the hot-dry lands: a study in exotic forestry.

421. Lindh, Thornsten Lennartson. The mechanism of development of wet strength paper with urea-formaldehyde resin.

422. Long, Norman Goodrich. Internal treatment of paper with phenolformalhedyde wet strength resin.

423. McLaughlin, William Edwards. Logetronic prints vs. conventional prints for tree height measurements.

424. Mayer, Warren C. The bleaching of groundwood pulp yith sodium boronhydride.

425. Meckert, Donald Cramer. Proposed accounting procedures for management control purposes in forest management.

426. *Meyer, John A. Studies in the pyrolysis of organic compounds.

427. Morrison, Edward Dixon. Vinyl benzoate: the kinetics of polymerization and properties of the polymer.

428. *Mukherjea, Sukumar. A manual of the genus *Fomes* for India, Pakistan, and Burma.

429. *Patric, Earl Francis. Some properties of the small mammal populations of the Huntington Wildlife Forest.

430. Reyes, Aurora C. Studies of wood hemicellulose: isolation of hemicellulose from alkaline liquors and properties of hemicellulose as beater additives.

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462. Dyrness, Christen Theodore. The effect of logging and slash burning on certain physical properties of forest soils.

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492. Merriam, Lawrence Campbell, Jr. Forest management procedures for the timbered lands of the Oregon State Highway Commission.
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501. Frank, Robert McKinley, Jr. Pennsylvania markets for primary forest products.
502. Harms, William Robert. The effect of clear-cutting in strips on reproduction in a Virginia pine stand.
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549. Stensrud, Russell Kenneth. A study of some problems involved in gluing refractory Douglas fir.

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552. Vannby, Karl-Gustaf. Forestry time studies in Sweden.

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554. Crawford, Robert James. A study of the effects of seasoning on the permeability of wood to liquids.

555. Larson, Merlyn Milfred. Root development of ponderosa pine seedlings as related to seed size and germination date.

556. Meister, Kenneth Richard. Economic planning for liquidation of second-growth timber.

557. Nelson, James Warren. Soil properties related to vegetation and time on the Kautz Creek flood area, Mount Rainier, Washington.

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561. *Larson, Philip Rodney. Effect of environment on the percentage of summerwood and specific gravity of slash pine.
562. *Walters, Charles Sebastian. Factors affecting the soaking treatment of basswood at low temperatures.
563. *Winer, Herbert Isaac. History of the Great Mountain Forest, Litchfield County, Connecticut.

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566. *McLintock, Thomas Frederick. Physical properties of the soils of the spruce-fir region of Maine and their relation to site index of red spruce.
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574. *Waters, William Eugene. The ecological significance of aggregated distributions with special reference to forest insects.
575. Weetman, Gordon Frederick. Mor humus in relation to boreal forest conditions: a literature review.

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